ORDER

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BATTERY THEORY AND SELECTION GUIDELINES

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RECORD OF CHANGES

DIRECTIVE NO. 6980.24A

CHANGE TO BASIC	SUPPLEMENTS			OPTIONAL USE	CHANGE TO BASIC	SUPPLEMENTS			OPTIONAL USE

FOREWORD

This order contains the information necessary to properly select and size batteries for either existing or proposed Federal Aviation Administration (FAA) equipment or facilities which are or will be dependent on battery systems for backup electrical power.

The rechargeable batteries which have been determined to be most suitable for application to the present and future FAA requirements are discussed herein. In each instance where a battery type is concerned, theory and chemistry in addition to operating parameters are covered in detail.

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CHAPTER 1. GENERAL

1. PURPOSE. This order provides battery theory and selection procedures for new and replacement secondary (rechargeable) batteries for application in FAA equipment and facilities. Battery facility design considerations are included as chapter 4. This order be should be used in conjunction with FAA Order 6980.26, Battery Backup Power Systems - Theory And Selection Guidelines, when developing requirements for a complete direct-current (dc) battery operating standby power distribution system.

2. DISTRIBUTION. This order is distributed to branch level in the Program Engineering Service and Systems Maintenance Service in Washington headquarters; to branch level in the regional Airway Facilities divisions; and to branch level in the Facility Support Division and the FAA Academy at the Mike Monroney Aeronautical Center.

3. CANCELLATION. This order cancels Order 6980.24, Battery Theory and Selection Guidelines, dated February 7, 1983.

4. ACTION. The battery theory and selection procedures given in this order shall be used to select and size new and replacement batteries for FAA equipment and facilities.

5. BACKGROUND. In the past, the FAA has depended primarily on engine generators to provide stand-by power to its facilities. Advances in solid-state technology and increased use of direct-current-powered electronic equipment has prompted the agency to investigate other sources of stand-by power. In employing these systems, the selection of the optimum battery is critical. This order has been revised to provide more detailed information and guidance in the selection of the most cost effective battery system. In addition, the battery facility design chapter has been expanded to include more considerations to improve battery performance, battery life and human safety.

6. DEFINITIONS. The definitions of selected words used in the text of this order are provided in this paragraph. These selected words are either not of wide and ordinary use, or the meaning of the word as used herein is different from ordinary or normal usage.

a. Ampere-Hours. The product of direct current in amperes, multiplied by the time in hours that the current exists.

b. Battery. An electrochemical energy storage device, consisting of one or more cells.

c. C-Rate. Discharge or charge current rate in amperes; numerically equal to rated capacity of a cell in ampere-hours.

d. Cell. A single electrochemical couple. A cell consists of a container, a positive plate or group of plates connected to the positive cell terminal, a negative plate or group of plates connected to the negative cell terminal, and electrolyte.

e. Cell Reversal. Electrochemical reversal of polarity of the plates of a secondary battery cell due to forced discharging (reversed polarity charging) after the cell voltage has decreased to zero volts.

f. Cell Voltage. The voltage measured at the battery cell terminals.

g. Charge, State of. Condition of a cell in terms of the discharge capacity remaining in the cell relative to the discharge capacity of a fully charged cell.

h. Charge Rate. The current at which a secondary cell or battery is charged. It may be expressed in amperes or as a fraction or multiple of the battery's capacity (capacity considered as if delivered in 1 hour). For example, the 10-hour charge rate of a 4-ampere-hour cell is $C/10 = 4/10 = 0.4A = 400mA$.

i. Charge. Process of supplying electrical energy to a battery.

j. Cycle. One sequence of battery discharge and recharge.

k. Cycle Life. The total number of discharge-recharge cycles delivered by a battery until the battery is unable to perform satisfactorily.

l. Deep Discharge. Withdrawal of at least 80 percent of the rated capacity of a cell or battery.

m. Depth of Discharge. The percentage of rated capacity to which a cell or battery is discharged.

n. Discharge. Withdrawal of electrical energy from a battery.

o. Discharge Rate. The current at which a battery is discharged. (See Charge Rate.)

p. Dry Charged. A battery that contains cell plates in the charged condition but does not contain electrolyte.

q. Electrolyte. The material that conducts the ions between the positive and negative plates of a battery cell.

r. Energy Density. Ratio of cell energy to weight or volume (watt-hours per pound or watt-hour per cubic inch).

s. Float Charge. The condition of a secondary battery being maintained in the fully charged state by steady application of charging power (constant voltage or voltage limited) sufficient to overcome internal battery power losses at the applied voltage but not sufficient to cause significant gas evolution within the battery cells.

t. Internal Resistance. Resistance to electric current inside the battery.

u. Open-Circuit Voltage. The no-load voltage of a cell or battery measured with a high-resistance voltmeter.

v. Pilot Cell. One or more cells that are used as a general indicator of the entire battery in regards to voltage, specific gravity and temperature.

w. Primary Battery. A battery designed to be discharged and then discarded; not designed to be recharged.

x. Rechargeable. Designed to be electrically discharged and recharged for multiple cycles. (See Secondary Battery.)

y. Secondary Battery. A battery which can be recharged after being discharged under specified conditions of use.

z. Self-Discharge Rate. The rate at which a battery loses capacity when standing open-circuit.

aa. Separator. A porous, nonconductive, material placed between positive and negative plates.

bb. Trickle Charging. Method of charging in which a secondary cell is connected to a constant-current supply that maintains the cell in fully or near fully charged condition (not used for recharging).

cc. Wet Charged. A charged battery that is filled with electrolyte.

7. OBJECTIVE. The objective of this publication is to provide design engineers and installation technicians with pertinent information which will aid in selecting and installing the optimum secondary battery system in facilities and equipment controlled by the FAA.

8. SCOPE. This order addresses lead-acid and nickel-cadmium-alkaline secondary batteries which are most suitable for present and near future applications in FAA facilities and equipments. Information presented in the following chapters will give the

reader an understanding of basic battery theory, guidance for selecting an appropriate battery to use in equipment or facilities, and a discussion of battery facility design considerations.

CHAPTER 2. BATTERY THEORY

9. BASIC THEORY. Batteries store and provide direct current electricity through internal electrochemical reactions. The electrochemical reactions are termed oxidation and reduction reactions. Oxidation is defined as a reaction in which the state of a substance becomes more electrically positive. In reduction, the substance becomes less electrically positive. Oxidation can be considered as the loss of electrons by a substance; reduction as the gain of electrons by a substance. The substances involved in these reactions are the active materials in the battery electrodes (plates).

a. The negative battery terminal is connected to the negative battery plate (spongy, metallic lead in a lead-acid battery and metallic cadmium in a nickel-cadmium-alkaline battery). The negative plate is called the cathode plate because of the electrochemical ionization reactions associated with it. On discharge, the anode plate undergoes an oxidation type of reaction, giving off electrons to the external circuit and receiving negative ions from the electrolyte. The process is reversed during charging. (Refer to an electrochemical textbook for a discussion of cation and anion preferential adsorption.)

b. The positive battery terminal is connected to the positive battery plate (lead peroxide in a lead-acid battery and a nickel plated steel in a nickel-cadmium-alkaline battery). The positive battery plate is called the anode plate because of the associated electrochemical ionization reactions. On discharge, the cathode plate undergoes reduction, receiving electrons from the external circuit to form negative ions with the electrolyte, the process being reversed during charging.

c. The battery electrolyte is the medium for ionic exchange in the electrochemical reactions. It is contained within each cell as a liquid or as a paste or jelly. Liquid electrolytes may be free to move within the cell or held in place by a mat or spongy material.

d. All batteries follow this basic electrochemical principle, varying in the materials utilized. Various materials are chosen for construction of the electrodes and formulation of the electrolyte to provide certain characteristics (such as more energy per weight, more energy per volume, lower cost of construction, longer cycle life (secondary batteries), less affected by temperature extremes, etc.), depending on the requirements of the particular situation. The materials that react with each other in an electrochemical reaction and the potential they generate in a cell can be determined by referring to an electromotive series in a chemical reference publication. The material higher in the series will be the anode and the other will be the cathode. The difference between the electromotive force (emf) values in the electromotive series will predict the total potential between the electrodes of a cell. As the materials in the battery react with one another, the reaction will slow down as the material is exhausted. In the lead-acid battery, electrons are being drawn out of the cell rapidly, the material next to the electrodes will react and use up the electrolyte. This condition, called stratification, will reduce the battery output until the electrolyte from the remainder of the cell electrolyte diffuses to the area next to the electrodes. This resistance to the electrochemical reaction may be seen as one cause of internal resistance in the electrochemical cell. The electrical resistance of the internal electrical circuit (metal straps and grids) also contributes to the internal resistance of the battery.

e. Battery ratings are measures of battery performance. Typical ratings which may be encountered are voltage, capacity, discharge current, and ambient temperature.

(1) Voltage is typically given as a NOMINAL value, the term nominal being somewhat misleading. Possibly nominal load voltage value would be a better choice, but the desired result is a convenient indication of the battery voltage for general description, such as a 12-volt car battery. The stabilized, open circuit voltage of a single charged lead acid cell is approximately 2.05 volts at 1.200 specific gravity (It should be noted that voltage will vary with electrolyte concentration). That of a single, charged nickel-cadmium-alkaline cell is approximately 1.23 volts. Battery voltage is determined by cell chemistry and the number of cells electrically connected in series within the battery. A 12-volt car battery would require 6 series-connected lead-acid cells or 10 series-connected nickel-cadmium-alkaline cells.

(2) Capacity is a measure of the battery's capability to provide current for a period of time. Because the battery voltage decreases as it continues to provide current, the capacity is associated with some voltage value (referred to as cutoff voltage) at which further discharging is no longer useful. Basically, capacity is the time integral of the discharge current. For many applications, capacity is stated in terms of ampere-hours, e.g., the product of discharge current in amperes multiplied by the time in hours that the current exists before the battery voltage decreases to the cutoff voltage. See appendix 1 for calculating the capacity required by complex discharge current loads. For automotive batteries, the Society of Automotive Engineers' Standard J537j describes rating tests for reserve capacity and cold cranking. The reserve capacity rating indicates the number of minutes that the test battery can be discharged at a constant 25 amperes before the battery voltage decreases to 1.75 volts per cell (in an 80 degree fahrenheit ambient). The rating for cold cranking indicates the constant, continuous current that the battery will provide for a standard

test time period (30 seconds or 90 seconds) with the voltage remaining above cutoff (1.2 volts or 1.0 volts per cell) at a standard test temperature (0 or -20 degree fahrenheit). Capacity capability is affected by the magnitude of the discharge current (rate) and temperature, as well as the quantity of active plate materials and electrolyte.

(3) Discharge current or rate capability may be expressed in terms of a C-rate, hour rate, or amperes. Battery discharge current capability is dependent upon factors such as internal electrical resistance, temperature, state of charge, and plate current density (amperes per unit area of plate surface). As the discharge current is increased, the available battery capacity is decreased. The capacity change is more pronounced for lead-acid batteries than for nickel-cadmium-alkaline batteries, and varies with battery design and construction.

(a) The hour rate is commonly encountered and describes the number of hours for discharging the battery at constant current to a cutoff voltage. An eight-hour rate means that the battery capacity is discharged in eight hours. Typically, the nominal, or baseline capacity rate for lead-acid stationary batteries is the 8-hour rate. For nickel-cadmium-alkaline stationary batteries, the 5-hour rate capacity is commonly listed. The discharge current (amperage) value of a particular hour rate is the battery capacity value divided by the hours of discharge. For the same battery, each different hour rate will have a different capacity value associated with it.

(b) Occasionally, C-rates may be encountered. C-rates are the discharge current values expressed as a fraction or multiple of the baseline or nominal capacity of the battery. Some commercial battery sales brochures are ambiguous in this respect, indicating that C-rates are another way of describing hour rates. This is only true for the baseline or nominal rate. For a battery in which nominal capacity (C) had been determined at the 8-hour rate, the discharge current values for the 5-hour rate and C/5 rate would each be different values, as would the resulting capacity values. The discharge current for the 5-hour rate would be slightly less than the discharge current for the C/5 rate. But, for this particular battery, the discharge current values and resulting capacity would be the same for the 8-hour rate and C/8 rate. For C-rates, the discharge current value, or amperage, is the nominal (or baseline) capacity multiplied by the stated fraction or integer.

(c) Discharge rates in terms of constant power, or watts, may be specified meaning that as the battery discharges, the current is increased to offset the decline in battery voltage such that the product of voltage multiplied by current is maintained at the wattage specified. A descriptive discharge current capability rating is a statement of the constant, continuous current (amperes) that a battery is designed to supply, but this rating is not always available in commercial sales brochures.

(d) High-rate, low-rate, and medium-rate are frequently encountered terms, but they are relative indications, translating into amperes only when the basis for comparison is known. A 1 C or C/2 rate might be thought of as medium rate, 2 C or 3 C as being a high rate, and C/4 or C/8 as a low rate, but no convention has been standardized. Changing discharge rates can result in a different capacity value due to limitations on the rate of electrochemical reactions at the plate surfaces, diffusion of fresh electrolyte to the plate surfaces,and changes in battery internal temperatures affecting internal electrical resistance. As the discharge rate increases, the capacity available tends to decrease.

(4) A temperature rating indicates that a battery has been designed for use within a specific stated temperature range. An example would be a lead-acid battery designed for low (relative) temperature operation through use of electrolyte having higher specific gravity than that used in a battery designed for high temperature operation. Temperature rating is occasionally confused with rating temperature, rating temperature being the specific temperature at which a test is accomplished (such as the 0 degree fahrenheit rating temperature for the automotive battery cold cranking test). As the temperature of a particular battery is increased, the available capacity tends to increase. To convert temperatures between degrees Centigrade and degrees Fahrenheit, see appendix 2.

10. PRIMARY CELLS. Primary cells are not rechargeable. Primary cell batteries are consumable in that they are exhausted by degrees as the chemicals which they contain react with one another to generate electricity. When their chemical components will no longer generate electricity, they must be disposed of in an approved manner. Primary cells are available in many electrochemical combinations for applications ranging from carbon zinc flashlight cells to lithium-thionyl chloride cells for military use. While true primary cells are not rechargeable, some commercially available primary cells can be recharged to varying degrees under precisely controlled conditions. Recharging of primary cells is not recommended in FAA applications. Primary cells tend to have higher energy densities (or capacities) and much better charge retention than secondary batteries.

11. SECONDARY CELLS. Secondary cells or storage batteries are similar to primary cell batteries in their ability to produce electricity through the reaction of chemicals with one another. The difference is that secondary cells can also be completely recharged and discharged again. The repetition of discharging and recharging is called cycling. Secondary cells are available

in numerous electrochemical combinations, as are primary cells. However, only lead-acid and nickel-cadmium-alkaline are normally used in FAA facilities and equipment, due to their reliability, applicability and life cycle cost advantage. The FAA nomenclatures for the types, classes, and styles of secondary cells used is described in the following paragraphs. Basically, type will indicate the battery application, class will indicate battery maintainability, and style will indicate battery position sensitivity or free electrolyte. The types, classes, and styles are for FAA purposes, and may not be the same as manufacturer's designations.

a. Type I. Stationary stand-by float (for uninterruptible power supplies, switch gear, communications).

b. Type II. Stationary engine generator starting.

c. Type III. Vehicle starting and auxiliary power. (Sometimes referred to in commercial literature as automotive starting, lighting, and ignition batteries.)

d. Type IV. Deep discharge cycle motive. (Forklift trucks, golfcarts, etc.)

e. Type V. Emergency lighting, portable test equipment.

f. Type VI. Renewable energy storage. (Used with solar cell, windmills, etc.)

g. Class 1. Regular maintenance.

h. Class 2. Low maintenance.

i. Class 3. Sealed, no maintenance.

j. Style A. Free electrolyte, or orientation or attitude sensitive.

k. Style B. Non-spillable electrolyte and not orientation or attitude sensitive (Note: normally, Style B is applicable only to Class 3 batteries.)

12. APPLICABILITY. Each of the types, classes, and styles listed (using FAA nomenclature) is normally designed and constructed with distinguishing performance characteristics and features most suitable for particular uses. In most applications, several or all battery types could be used as an expediency, since all can supply power. But the use of a battery type outside its design application does not take full advantage of its particular performance characteristics or features and will probably result in reduced capability. For instance, Type III

vehicle starting and auxiliary power (automotive) batteries will function in stationary standby float applications, but may experience shortened life when frequently deep-discharged. And the use of automotive-type batteries for emergency (stationary standby) systems is specifically prohibited by the National Electric Code of 1987 (Article 700-12(a)). In order to determine the appropriate type, class, and style for a battery, thorough consideration of the particular application is necessary.

a. Stationary, standby float (Type I) batteries should be used in stationary applications to provide emergency or backup power when the primary power (normally commercial electric line) fails. The equipment that these (Type I) batteries will power normally consists of uninterruptible power supplies, switch gear, such as relays, and communication receivers and transmitters.

(1) Distinguishing characteristics of the Type I battery application are stationary operation, continuous battery charging (float operation) when primary power is available, long duration (hours) discharging at low to moderate rates (although some applications involve complete discharging at high current in as few as ten minutes or momentary loads with high surges) and moderate to high capacity in terms of ampere-hours. Battery system voltages typically range from 12 volts (or lower) to more than 500 volts.

(2) The typical environment of a Type I battery is normally indoors at moderate humidity, with a moderately narrow temperature range, and free of vibration, shock, and acceleration. When the Type I battery is installed in a battery box located out-of doors, provisions should be incorporated to minimize temperature extremes, or a higher capacity battery may be required. The Type I battery is normally installed inside equipment or in racks bolted to the floor near the equipment.

(3) In usage, the installation is typically permanent for the life of the battery. A Type I battery normally experiences infrequent (one or less per month) discharges to varying depths (100 percent or less). The Type I battery is maintained at full state of charge, ready for use condition, by float charging from a constant voltage source. Recharges after discharges are normally completed within from 2 to 24 hours.

(4) Due to the normally large sizes, manufacturers supply the Type I battery as individual cells or cell packs (2 or more cells in the same assembly) for assembling into a complete battery at the installation site.

(5) Manufacturers' designations for stationary, standby float (Type I) batteries will vary. One manufacturer may list a battery according to a particular intended use such as

switchgear, while another may list a battery with almost the same performance characteristics as high rate/short duration or as high performance. Or, a manufacturer may list the same battery part number under several different applications. The intended use and battery performance requirements should be described as accurately as possible in order to assist technical personnel in selecting which batteries will give the required performance and to allow effective review of battery proposals received in response to solicitation. Class and style are optional, depending upon the needs of the particular application, FAA policy, and commercial availability. However, Type I batteries are typically Class 1 or Class 2, and Style A.

b. <u>Stationary engine generator starting</u> (Type II) batteries should be used for starting both gasoline and diesel, stationary internal combustion (reciprocating) engines that power electric generators.

(1) <u>Distinguishing characteristics</u> of the Type II battery application are stationary operation, daily boost charging controlled by a timer and temperature voltage relay with equalize charging capability, and high current starter motor discharge loads lasting up to one minute. Battery system voltages are normally 32 volts.

(2) <u>The environment of</u> a Type II battery may be installed outdoors in a well ventilated covered box or indoors in racks near the engine generator. When located outdoors, the battery will be subjected to a wide temperature and humidity range dependent on the local climate.

(3) <u>In usage</u>, the Type II battery may experience 1 or 2 engine starts per month. The discharges are at high current, but normally last only 2-5 seconds. Requirements for 30 second or 60 second engine cranking capability are demonstrated by periodic testing. The Type II battery is maintained fully charged by boost charging on a daily basis, with equalize charging when needed.

(4) <u>Due to reserved time</u> for engine testing, possible frequent restarts and adverse temperature extremes, the Type II batteries are large. Additionally, these battery cells employ large numbers of plates to obtain high total plate surface areas for high rates, limitations on the physical height of the cells to reduce electrolyte stratification problems, generally heavier grids and straps to reduce internal resistance and resist corrosion, and wrapping of the positive plates to prevent shedding of active material.

(5) <u>In practice</u>, Type II batteries are generally the lead-acid type, due to the lower initial cost as compared to nickel-cadmium-alkaline batteries, numerous commercial sources,

and familiarity. Typically, four (4) cell batteries are used in FAA systems. Class and style are normally Class 1, Style A.

c. Vehicle starting and auxiliary power (Type III) batteries are sometimes referred to in literature as automotive starting, lighting and ignition batteries, or simply car batteries. Under this (Type III) grouping are included recreational vehicle (RV) batteries, and marine batteries. Farm machinery batteries, lawn tractor batteries, motorcycle batteries, and construction and industrial machinery batteries are also included. Type III batteries should be used for these applications.

(1) Distinguishing characteristics of the Type III battery applications are their use to provide electric power to engine starting motors in mobile equipment and vehicles and to provide auxiliary electric power to these vehicles and equipment. The Society of Automotive Engineers Standard SAE-J537, which standardizes these batteries, adds the requirement that the equipment and vehicles be equipped with regulated battery charging systems. The battery voltage is commonly 12 volts, although some batteries are available in other voltages.

(2) The environment of a Type III battery is an installation in a battery box, compartment, or space in or near the engine compartment of the vehicle or equipment. The battery will be subjected to the widest temperature range of all types. The temperature range is dependent upon the local climate and upon the upper ambients reached in or near the engine compartment. The battery will be exposed to humidity levels to 100 percent, including condensation due to temperature changes. The battery will also be subjected to vibration and low levels of mechanical shock and acceleration.

(3) In usage, the battery may experience varying demands, ranging from several engine cranking discharges per day to very few discharges per month, depending on the vehicle or equipment usage. Most engine starts occur within 5 seconds or less, but longer durations or several attempts may be necessary in some instances. The battery is recharged immediately after starting use (unless the equipment has malfunctioned). It may also provide auxiliary power to lights, radios, or accessories when the engine is not running. Because of the extreme conditions and demands, as well as thinner plate construction, these batteries tend to shorter life times.

(4) Because these (Type III) batteries are for use in mobile applications and don't normally require high (relative) capacity, they tend to be portable by one person. They are moderate in physical size and are designed with large cell plate surface areas to provide high cranking current. RV and some marine batteries (commercial designations) tend to have a lower

discharge rate capability--intended more for lighting or auxiliary power--and greater tolerance of discharge to deeper levels with some delay before recharging through use of thicker cell plates or heavier plate grids. RV or marine batteries may be connected in parallel to provide higher starting current capability.

(5) In practice, Type III batteries are generally of the lead-acid type, due to low cost, numerous commercial sources, and familiarity. In aircraft applications however, the weight comparison and extremely high starting current needs usually result in the selection of nickel-cadmium-alkaline batteries. SAE Standard J537 should be consulted for standard sizes and terminal connections of Type III batteries. Class and style are optional (most new car batteries are currently Class 2 or Class 3, and Style A), depending on the particular application needs, FAA policy, and commercial availability.

d. Deep discharge cycle motive (Type IV) batteries should be used in vehicles requiring batteries for motive power. These vehicles include industrial electric forklift trucks and transporters, golfcarts, and electric vehicles.

(1) Distinguishing characteristics of the Type IV battery application are varying discharge loads and extended periods (days or weeks) in a partially discharged state. Battery system voltages will be from 6 to 48 volts (or higher for some electric vehicles).

(2) The environment of a Type IV battery will depend upon the application - it may be indoors in a factory resulting in a relatively narrow temperature range or out-of-doors with the temperature range determined by local climate. The battery will be subjected to minor (low) levels of vibration, shock, and acceleration.

(3) In usage, the battery will be subjected to moderate discharge rates with short duration high rate demands. The battery may experience complete discharge in one day, possibly to such depth that the vehicle becomes immobile. Or, the battery may be discharged a small percentage of total capacity each day for several days or weeks resulting in extended periods in a state of partial discharge.

(4) Type IV batteries tend to be large, approaching limits dictated by equipment mobility, in order to provide high capacity and high power levels. The extended periods of partial discharge and possible deep discharging make the antimony alloy grids more suitable in Type IV batteries, although calcium alloys may result in better charge retention during long stand times.

(5) <u>In practice</u>, Type IV batteries tend to be of the lead-acid type, due to the large capacities and lower initial cost. They also require more frequent equalize charging due to long stand times and deep discharging. Higher water consumption results because of equalize charging. The Society of Automotive Engineers has established Aerospace Recommended Practice ARP 1817 to describe industrial, lead-acid batteries for use in electric powered ground support equipment, offering a specification-type of battery description which may be useful when reviewing manufacturers literature. Class and style are normally Class 1, Style A.

e. <u>Emergency lighting or portable</u> test equipment batteries (Type V) are used to provide electric power to building lights that operate when commercial power fails or to operate portable test equipment. Emergency lighting in buildings is required by building codes to illuminate exit ways and exits for occupants. Some portable test equipment requires electric power for operation and an internally installed power source may be most suitable.

(1) <u>Distinguishing characteristics</u> of the Type V battery application are relatively low and steady discharge currents with recharging when commercial power is available. They are maintained in a full state-of-charge by float charging between uses. Because of the low power and short duration discharges required, or portability needs, they tend to be small in size.

(2) <u>The environment</u> of a Type V battery is typically that for an indoors area occupied by personnel. Portable test equipment might experience intermittent use out-of-doors, but environment extremes would be limited by the equipment operating capability. Most portable test equipment would, however, require a battery with all-position capability. And some portable test equipment would experience low level mechanical shock.

(3) <u>In usage</u>, the Type V battery installed in emergency lighting systems will experience essentially the same operation as the Type I stationary battery, discharging when primary power fails. Portable test equipment batteries would probably be used more often. Because the Type V batteries power equipment and lighting that may not have voltage cutoff protection, Type V batteries are more likely to experience deep discharging, continuing until the equipment fails to provide required performance and sometimes until the battery voltage reaches zero. Emergency lighting in exit ways may be required for only a few minutes which would result in a high rate battery discharge (15 minutes would be a 4 C rate). Most portable test equipment applications would be at a much lower rate. Type V battery discharge currents must be accurately described.

(4) Due to the normally low total watt-hour (low total power or short duration discharge) needs of emergency lighting systems and portability requirements for portable test equipment, Type V batteries tend to be small in physical size. Some stationary emergency lighting systems may use small Type I stationary batteries, provided that the equipment has discharge voltage cutoff protection. Emergency lighting batteries should generally be Class 2 or Class 3, requiring low or no maintenance and may be Style A (unless all-position capability will be required) or Style B. Portable test equipment batteries must be Class 3, Style B, to allow for the possibility of all position operation.

(5) In practice, Type V batteries are commercially available in both lead-acid and nickel-cadmium-alkaline electrochemistries. The selection of electrochemistry may be dictated by initial cost, sizes available, life cycle cost analysis, area chemical compatibilities, or keeping the same part number when making replacements. Suitable batteries are usually available from numerous sources. (When desirable to operate without charging capability, primary batteries might be considered due to their long stand time capability and higher energy density (capacity).) Numerous emergency lighting systems currently use low - or no - maintenance cells (Class 2 or Class 3). Portable test equipment tends to use Class 3, Style B nickel-cadmium-alkaline batteries (installed as cells) when the required capacity is relatively small and the battery is installed inside the equipment. When the battery is carried along with the equipment, but not mounted on or in the equipment, Class 3, Style B lead-acid batteries tend to be used (except in hospital equipment, which usually employs nickel-cadmium-alkaline batteries).

f. Renewable energy storage batteries (Type VI) are used for electrical energy storage with solar cells, wind-driven generators, or other renewable energy sources. These systems may be used in locations where access is limited or in remote areas away from commercial power sources. As Type VI batteries are categorized based on the use of renewable energy sources for charging, they can be applied in almost any system where sufficient renewable energy (wind, solar, geothermal, etc.) is available, along with adequate energy conversion and charging devices.

(1) Distinguishing characteristics of the Type VI battery application are normally a daily cycle routine of discharge while the renewable energy source is unavailable and recharge when the renewable energy source becomes available. These applications normally use a battery of sufficient capacity

to operate the system for more than one day (cycle) - up to 4 or 5 days in some cases - without significant recharge, in order to allow for the possible unavailability of the renewable energy source.

(2) The environment of a Type VI battery is typically that of a covered battery box, equipment compartment, or other shelter which has no ambient conditioning (heating or cooling) other than venting to the ambient air outside the facility. The temperature range will be determined by the local climate and insulating performance of the installation. The environment of a typical application will be free of vibration, shock, and acceleration. Humidity levels may reach 100 percent, including condensation due to temperature changes.

(3) In usage, the Type VI may not be fully recharged after each discharge period. However, the charging system should be capable of eventually returning the battery to a state of full charge for more than half of the battery lifetime. Discharge rates will vary according to the application. Discharge capacities will be determined by the individual cycle needs and the desired amount of reserve capacity for extra cycles without significant recharge, as well as battery charger capability.

(4) Due to possibly limited accessibility of the intended installation, these (Type VI) batteries may or may not require portability considerations for physical size and style (Style B versus Style A). Also, accessibility may limit maintenance visits, requiring Class 2 or Class 3 (low or no maintenance).

(5) In practice, Type VI batteries are available from several manufacturers, sometimes under the description of photovoltaic or solar batteries. Battery use in renewable energy storage applications requires thorough consideration of charging capabilities, availability of the renewable energy, and the needs for assurance of availability of equipment operating power, in addition to discharge loading.

13. LEAD-ACID.

a. Theory and Chemistry. The lead-acid battery consist of positive and negative electrodes which are separated from each other, sequenced in pairs, and immersed in an electrolyte solution of sulfuric acid. In the fully-charged condition, the active material of the positive electrode is lead dioxide (PbO_2), and the active material of the negative electrode is lead (Pb). As the cell is being discharged, the lead dioxide of the positive electrodes, and the lead of the negative electrodes is converted to lead sulfate utilizing the sulfuric acid electrolyte by the following reaction:

Charged Condition		Discharged Condition
$PbO_2 + Pb + 2\ H_2SO_4$	$\rightleftarrows$	$2\ PbSO_4 + 2\ H_2O$

That is, lead, lead dioxide, and sulfuric acid are consumed, and lead sulfate and water produced. During the process, the electrodes remain insoluble: lead, lead dioxide, and lead sulfate are relatively insoluble in the sulfuric acid. Battery capacity is dependent upon the amount active materials in the positive and negative plates, the quantity and concentration of the electrolyte, and the diffusion rate of the electrolyte through the separating materials. The conductivity of the active materials, the supporting network, and plate straps also enter into the discharge characteristics.

b. The Lead-Acid System Is Reversible. When current is forced through the cell in the opposite direction of current flow during discharge, chemical reactions convert the discharged materials (lead sulfate and water) to lead dioxide and lead, and release sulfuric acid into solution. A single discharge followed by a charge is defined as a cycle. After a number of cycles, a cell will fail to deliver its rated capacity because of certain irreversible changes that occur during cycling. The types of changes, and consequently cycle life, varies among the different lead-acid systems, and are sensitive to such parameters as depth of discharge, degree of overcharge, charge rate, environment during service, electrode construction, and separator materials.

c. Capacity Ratings. One measure of capacity is ampere-hours and is measured by multiplying the current drain times the duration of the current drain. The Ampere-hour rating of a lead-acid stationary battery is based on an 8-hour discharge period to an end voltage of 1.75 V/c. The ampere-hour rating of a battery will decrease as the discharged rate is increased. The ratings listed for specific model batteries are usually based on a specific gravity of 1.210 or 1.215 although for specific applications (e.g., photovoltaic) and other type of battery construction a more concentrated (higher specific gravity) electrolyte may be used. For a specific application such as low or high temperature environments, the normal specific gravity electrolyte of a standard battery can be replaced with electrolyte of higher or lower (respectively) specific gravity which will change the performance characteristics from that given for the battery with the normal specific gravity. Engine starting batteries are rated in cold cranking amps and reserve capacity. Cold cranking amperes is the number of amperes a battery will deliver at 0 degree fahrenheit for 30 seconds to a voltage of 1.2 volts per cell. The reserve capacity is the number of minutes a battery will provide 25 amperes to an end voltage of 1.75 volts per cell.

(1) Temperature Effects. Lead-acid batteries are sensitive to temperatures above and below the normal room temperature of 77 degree fahrenheit as listed in table 2-1 and the following paragraphs:

(a) High temperature shortens the life due to accelerated corrosion and deterioration of the plates and separators by the electrolyte. Constant ambient temperatures of 15 degree fahrenheit or more above 77 degree fahrenheit will typically cut the life in half. This affect can be partially compensated for by reducing the specific gravity (activity) of the electrolyte.

(b) Low temperature will reduce the available capacity of the battery. Dropping from the normal of 77 degree fahrenheit to 40 degree fahrenheit will give approximately 3/4 the rated capacity. As the battery is discharged, the electrolyte specific gravity is reduced, thereby raising its freezing point and susceptibility of the battery to permanent damage. A discharged stationary battery could freeze at a temperature as high as +16 degrees fahrenheit constant ambient temperature.

(2) Rate effects. The magnitude of the discharge current affects the total quantity of ampere hours that the battery can deliver before the battery voltage decreases to the cutoff value. Rate capability depends basically upon the total plate surface area for each plate polarity. the plate surface area determines plate current density for any given discharge current. High-rate cells have more and thinner plates than low-rate cell of the same physical size. As the discharge rate increases, the capacity available from any particular cell decreases. additional factors affecting battery capability are the electrical resistance of internal conductors, cell design

TABLE 2-1 LEAD-ACID BATTERY CAPACITY VS TEMPERATURE

Electrolyte Temperature	Percent Capacity and Discharge Rate	
$^{\circ}F$	8 Hour	1 Minute
110	110	117
90	105	108
77	100	100
60	90	88
40	77	73
20	62	58
10	54	49

geometry and construction, and chemical concentrations. Because of the many variables affecting rate, a single precise description of rate effects on capacity cannot be developed for application to all lead-acid batteries. Table 2-2 provides an example of rate effects on the capacity of a particular lead acid battery.

d. Charging.

(1) Float Charge. A fully charged battery will gradually lose some of its charge due to internal losses (termed self-discharge). Proper float charging supplies enough electric energy to over come these internal losses without causing significant gas evolution. Float voltage is higher than the open circuit cell voltage (see table 2-3).

(2) Equalize Charging. Equalize charging assures completion of recharge, eliminating cell voltage imbalances and electrolyte stratification. The schedule for periodic equalizing charges will be determined by the cell type and operating conditions (e.g., frequency and depth of discharges). Equalize charging may be necessary as often as monthly. And some batteries, such as low-maintenance (Class 2) and no-maintenance (Class 3) should never need equalizing (and may be damaged by heavy equalize charging). The antimony type lead-acid battery may require more frequent equalizing charges. The antimony battery will provide greater cycle life than the calcium battery when used for deep discharge cycling but at the penalty of more frequent equalize charges and higher water usage because of the equalize charging. Antimony does not retain its charge as well as does the calcium, due to higher self discharge losses. Equalize charging, while necessary in certain situations, must be

TABLE 2-2 EXAMPLE OF LEAD-ACID LOW RATE STATIONARY BATTERY CAPACITY* VERSUS RATE

DISCHARGE RATE	PERCENT CAPACITY
C/46	157%
C/18	139%
C/10	114%
C/8	100%
C/6	86%
C/5	79%
C/4	71%
C/3	52%
C/2	26%
1C	1%

*NOTE: Capacity to cutoff voltage of 1.75 volts per cell, 77°F ambient, C is the capacity at the 8-hour rate.

carefully controlled to prevent battery damage due to water loss, increased grid corrosion, plate warpage (from too great of current), or excessive temperature. Along with hydrogen and oxygen evolved during overcharge of lead-acid batteries, stibine or arsine gases may be present. Stibine (SbH_3) is a poisonous gas resulting from any antimony present within the cell. Arsine, also a poisonous gas, results from the presence of arsenic in the lead plates. Stibine and arsine are removed with the other evolved gasses by proper facility ventilation. Equalize charging is indicated when the batteries are fully charged and:

(a) The temperature-corrected specific gravity of the pilot cell of a floating battery has dropped more than 10 points (e.g., from 1.215 to 1.205) below its full charge reading.

(b) When the voltage of a cell on float is more than 0.05 volts below the average of the cells in the battery.

e. Service Life. Exact discharge/recharge cycle life of cells is difficult to predict due to the effect of varying charge/discharge conditions (depth, rates, frequency of use) on cycle life. Batteries consistently over charged will experience a shortened life due to grid corrosion, over activity of the electrolyte from the increased temperature and voltages, and an increase in electrolyte concentration from water being driven off of the electrolyte. High current rates will also cause the plates to expand and contract and shed active material. Batteries not completely recharged will suffer the same problems as a battery allowed to stand discharged, resulting in a potentially permanent sulfation of the battery plates. Shock and vibration are harmful to the soft lead materials in a lead-acid battery,

TABLE 2-3. LEAD-ACID BATTERY CHARGE VOLTAGE

LEAD-ACID BATTERY TYPES	FLOAT VOLTAGES	EQUALIZE VOLTAGE
Lead Antimony	2.19V/C	2.30V/C
Lead Calcium	2.26V/C	2.34V/C
Automobile		
Maintenance-Free	2.245V/C	2.395V/C
Ordinary	2.010V/C	2.29V/C
Gelled Electrolyte	2.275V/C	N/A

causing loss of active materials from plates and structural damage. Cracks in the insulation material between plates will allow conductive deposits to form and internally short the cell. Poor maintenance can allow external shorting through conductive contamination of the battery case and internal contamination of the electrolyte which can reduce its activity, increase corrosive effects on the plates and connectors, and cause internal shorting, depending on the substance that causes the contamination. Salt water entering the battery can result in the release of chlorine gas, due to reaction with the positive plates. High-rate discharges to low end voltages will shorten a battery's life considerably. In general, a lead-acid battery should not be discharged below 1.75 V/c. A discharged lead-acid battery should not be allowed to stand for an extended period in a discharged condition or, because of sulfation, it may not accept a recharge. Recharge should be initiated immediately if possible, and within 2 days to minimize sulfation damage and grid corrosion. High-rate recharging of lead-acid batteries may also reduce their life through heating, plate warping, or capacity percent overcharge. Lead-antimony cells are capable of about 150 to 200 discharge/recharge cycles when discharged at the normal 8-hour rate to 1.75 volts per cell and recharged at a normal rate to 2.15 - 2.25 volts per cell. Under the same conditions, lead-calcium cells are capable of about 50 to 75 discharge/recharge cycles.

f. Storage. The storage area should be dry and clean. A storage temperature from 60 to 80 degrees fahrenheit is preferred. Battery storage (charged and wet) at temperatures below 20 degrees fahrenheit could result in freezing of the electrolyte in a wet cell (depending on the specific gravity) which may damage the cell. Storage at temperatures above 90 degrees fahrenheit can result in a shortened life, as well as faster self discharge. Dry charged cells can be stored up to one year without deterioration. The storage temperature should be as constant as possible. Wet charged cells should not be stored longer than 90 days without recharging. Large temperature fluctuations will cause air to enter unsealed dry charged batteries when they cool, and expel air as they become warm. Every time air enters the dry charged battery, it will bring moisture and air to the plate's active material, adversely affecting them. However, wet and charged cells must be given an initial charge within 3 months from the date of shipment if the battery is of the lead-antimony type and within 6 months if of the lead-calcium type, to avoid sulfation of the plates. Sulfation of the plates can adversely affect electrical performance and expected life. If an extended storage period becomes necessary, additional charges should be provided at 3 month intervals. The extended storage of wet, charged batteries is not recommended. Batteries that are to be removed from service and stored should be charged, cleaned and stored as described above for new wet, charged batteries.

g. Failure Modes. When the battery can no longer meet its performance requirements, it is considered to have failed. Causes of failure are normal ageing, manufacturing defects, improper maintenance, misuse, and damage.

(1) Batteries can suffer from reduced capacity which normally occurs gradually and is a failure mode that occurs with warning and will allow time to correct without an interruption in service. This type of problem occurs at the end of battery life and can be caused from contamination and/or active material shedding within the battery. Batteries also suffer from catastrophic failures such as open circuits and battery rupture. This will typically be due to poor construction or improper maintenance. This type of problem can occur without warning and cause unplanned interruption of service.

(2) The main causes of aging failures are grid corrosion, cell shorting, loss of active materials from plates, and sulfation. Grid corrosion is oxidation of the plate grids caused by overcharging and oxygen formation at the positive plate. As grids corrode, they become brittle and lose structural strength and capability to conduct electric current. Cell shorting, or contact between conductors of opposite polarity, can occur because of damage or accumulation of conducting material (shedded active plate material) that forms a bridge between plates of opposite polarity. Active material that is lost from plates can no longer participate in the electrochemical reactions, resulting in lost capability. Sulfation results from undercharging or remaining too long in the discharged state. After sufficient time to crystalize and harden, the sulfate can no longer be converted by charging.

14. NICKEL-CADMIUM-ALKALINE.

a. Theory And Chemistry. Operation of a nickel-cadmium cell involves little or no change in electrolyte concentration. The active material of both electrodes, in both charged and discharged states, is relatively insoluble in the alkaline electrolyte. Because of these and other properties, nickel-cadmium-alkaline cells are characterized by long life in both cyclic and standby operation, and by a relatively flat voltage profile within a wide discharge current range. In the discharged state, nickel hydroxide is the active material of the positive electrode, and cadmium hydroxide that of the negative. During charge, nickel hydroxide, $Ni(OH)_2$, is converted to a higher valence oxide. And at the negative electrode, cadmium hydroxide, $Cd(OH)_2$ is converted to a higher valence oxide. The overall reaction is:

Charged Condition				Discharged Condition	
Positive plate	Negative plate			Positive plate	Negative plate

$$2NiOOH + Cd + 2H_2O \rightleftharpoons 2Ni(HO)_2 + Cd(OH)_2$$

From the above formula it is obvious that the capacity is dependent only upon the amount of material in the positive and negative plates. The conductivity of the active materials, the supporting network, and plate straps also enter into the discharge characteristics of the nickel-cadmium-alkaline cells. A nickel-cadmium-alkaline cell is charged by forcing a direct current through the cell in the direction opposite that of the discharge current. In the discharged state, the material in the interstices of the positive electrode consists mostly of nickel hydroxide, and that in the negative is mostly cadmium hydroxide. During charge, nickel hydroxide is converted to higher valence nickel hydroxides ($NiOOH$; $Ni[OH]_3$), most of which are in the trivalent state. Oxygen may be evolved by the positive electrode during charge. The amount of oxygen generated is determined by the state-of-charge of the electrode, current density, and temperature. As the state-of-charge is increased, the fraction of the current utilized to convert the remaining nickel hydroxide is decreased. Similarly, when the current density is low (on the order of the C/100 rate), the charge efficiency is reduced to such a degree that the cell never becomes fully charged. At high temperatures the charge efficiency is lowered, and a higher minimum current density is required to effectively charge a cell.

b. Capacity Ratings. A measure of capacity is ampere-hours, measured by multiplying the current drain times the duration of the current drain. Large stationary nickel-cadmium-alkaline batteries are typically rated for several different discharge rates in the reference literature. The discharge rate affects the nickel-cadmium-alkaline battery capacity that can be withdrawn above cutoff voltage. Increasing the rate decreases the available capacity. However, when compared with lead-acid batteries, the magnitude of the change is much smaller. Table 2-4 provides an example of rate effects on the capacity of a particular nickel-cadmium-alkaline battery.

c. Temperature Effects. As with lead-acid batteries, temperature also affects the performance of nickel-cadmium-alkaline batteries. The effect on capacity, life, and the freezing temperature is discussed in the following paragraphs.

(1) Capacity. As with a lead-acid battery, the capacity of a nickel-cadmium-alkaline battery is dependent on the

electrolyte temperature and discharge rate. Table 2-5 lists the decrease in capacity for temperatures below 77 degrees fahrenheit for discharge rates of 8 hours and 1 minute of a typical nickel-cadmium-alkaline cell. The capacity characteristic varies between cell type more than with lead-acid batteries. The

TABLE 2-4 EXAMPLE OF NICKEL-CADMIUM-ALKALINE POCKET PLATE CELL CAPACITY* VERSUS RATE

DISCHARGE RATE	PERCENT CAPACITY
10-HOUR	105%
8-HOUR	103%
5-HOUR	100%
3-HOUR	96%
1-HOUR	81%
30-MINUTE	64%
1-MINUTE	5%

*NOTE: Capacity to cutoff voltage of 1.00 volts at 77 degrees fahrenheit ambient. The 5-hour capacity is the baseline or nominal rate.

manufacturer should be consulted for the discharge characteristics for a specific cell. The increase in capacity above 77 degrees fahrenheit is usually ignored and the life effect is also not significant unless temperatures are high enough (130 degrees fahrenheit continuous ambient) to do short term damage to the cells.

TABLE 2-5 NICKEL-CADMIUM-ALKALINE BATTERY CAPACITY VS TEMPERATURE

Electrolyte Temperature	Percent Capacity and Discharge Rate	
°F	8 HR	1 MIN
77	100%	100%
60	95%	90%
40	84%	78%
20	75%	68%
0	65%	57%
-20	56%	47%

(2) Freezing Temperature. The standard specific gravity of the electrolyte in a typical stationary nickel-cadmium-alkaline battery is 1.180 which is a safe condition down

to -25 degrees fahrenheit. For extremely low temperatures a specific gravity of 1.225 can be used which provides safe operation down to -54 degrees fahrenheit. Specific gravity does not change with state of charge in a nickel-cadmium-alkaline battery.

d. Charging.

(1) Float Charge. Nickel-cadmium-alkaline batteries operating at temperatures from 60 to 80 degrees fahrenheit are normally float charged at 1.40 to 1.42 V/c. Random variations in temperature from about 40 to 85 degrees fahrenheit will have no significant effect on the charging. If the operating temperature is consistently high or low, some adjustment in the float voltage must be made. This adjustment amounts to 1 percent per 8 degrees fahrenheit. At low temperatures the float voltage is increased and at high temperatures it is decreased.

(2) High-rate Charge. The batteries are recharged automatically by the charger following a discharge (e.g., power outage) at a voltage higher than the normal float voltage. This higher voltage is referred to as the high-rate charge voltage. Nickel-cadmium-alkaline batteries will accept current at a much greater rate than lead-acid batteries without permanent damage (e.g., buckled plates) as long as the battery is not allowed to heat to the point of boiling the electrolyte or softening the case material. Hence, the term high-rate charging. The recommended high rate charge voltage varies from 1.50 to 1.70 V/c depending on the manufacturer's cell type. High-rate recharging following a discharge can be avoided by raising the normal float voltage. However, the water loss will increase. Table 2-6 lists the effects of various float voltages on water consumption and recharging characteristics of typical nickel-cadmium-alkaline batteries.

e. Service Life. The life of a nickel-cadmium-alkaline battery is not affected by high temperature as much as lead-acid batteries. At a continuous temperature of 115 degrees fahrenheit the life of a nickel-cadmium-alkaline battery will be 65 percent of the life at 77 degrees fahrenheit while the life of a lead-acid battery will be only about 27 percent of the 77 degrees fahrenheit life. At 90 degrees fahrenheit the nickel-cadmium-alkaline battery life will be approximately 88 percent while the life of a lead-acid battery will be approximately 50 percent of the life at 77 degrees fahrenheit.

f. Storage. The storage area should be clean and dry. A storage temperature of 60 to 80 degrees fahrenheit is preferred. Storage at temperatures down to -10 degrees fahrenheit is safe. Storage at temperatures above 110 degrees fahrenheit should be avoided since at this temperature a shortening of cell life begins. Unfilled cells can be stored for an unlimited time. Filled cells that are to be stored for up to 1 year should be given a charge. Before storage the electrolyte level should be checked. Electrolyte of the proper specific gravity should be added if necessary to bring the level up. If the plates are exposed and electrolyte is not available just enough distilled or deionized water should be added to cover the plates. When electrolyte becomes available it can be added to bring the level up. The battery can then be charged and the electrolyte specific gravity adjusted to the correct value. Adjustment is accomplished by adding water or removing electrolyte and adding water if the specific gravity is high. If the specific gravity is low, the battery can be given an extended charge, which allows electrolysis to take place and then adding electrolyte.

TABLE 2-6. FLOAT VOLTAGE EFFECTS ON NICKEL-CADMIUM-ALKALINE BATTERIES

V/c	Watering Intervals	Recharging Characteristics
1.40-1.42	2-5 years	Equalizing charges required if complete discharges occur more often than once a year.
1.44-1.47	18-36 months	Battery will be fully charged even if complete discharges occur as often as once per month.
1.50-1.53	9-18 months	Battery will be fully charged even if complete discharges occur as often as once per week.
1.55-1.60	1-6 months	Battery will be fully charged even if complete discharges occur as often as once per day. Not recommended for continuous use because of excessive water consumption.

NOTE: Unlike lead-acid batteries, nickel-cadmium-alkaline batteries do not require periodic equalizing charges.

g. Failure Modes. When the battery can no longer meet its performance requirements, it is considered to have failed.

Approaching the end of life a nickel-cadmium-alkaline battery will gradually loose capacity. The only way to detect this type of failure is to run periodic capacity tests on the batteries. A more rapid type of failure is caused by internal shorting between plates of the battery cell. This type of failure is evidenced by the affected cell having a lower voltage reading on float than the other cells in the battery.

(1) Memory effect is an apparent loss of capacity occurring in some nickel-cadmium-alkaline batteries, small sealed cells, as a result of regular shallow discharging at the same rate to the same depth. When deeper discharging is attempted, the battery voltage drops off, as if fully discharged. Normally, capacity can be restored by reconditioning the battery with a few cycles of complete discharge and full recharge.

(2) Thermal runaway is a serious failure, basically being internal cell shorting during charge. In this condition, the separator material has deteriorated and internal shorting occurs. Internal temperatures rise and the charge current increases, driving up the temperatures further. As the electrical energy is dissipated internally, damage increases. The battery will get hot, smoke, release hazardous vapors, and may catch fire or explode. Nickel-cadmium-alkaline battery float charging should be accomplished using chargers with a low current limit to reduce the consequences of thermal runaway.

CHAPTER 3. BATTERY SELECTION

15. CHAPTER OVERVIEW. This chapter offers guidance for selection and sizing of secondary (rechargeable) batteries for application in FAA facilities and equipment. It is divided into 2 sections: section 1 describes the selection of new (original) batteries, and Section 2 discusses selecting replacement batteries. To assist in documenting battery requirements, section 1 includes a data sheet format for collecting information about the battery application. A quick reference guide, the Battery Selection Flow Chart, is included at the end of section 1.

SECTION 1. NEW (ORIGINAL) BATTERIES

16. SYSTEM APPROACH. The selection and sizing of secondary batteries is an important step toward ensuring satisfactory system operation. Battery selection may begin at the earliest time the electrical parameters of the equipment can be defined. Battery specifications and data published by manufacturers should be consulted when comparing electrical parameters of battery-using equipment with batteries that are commercially available. Selection of commercial batteries inevitably involves some degree of trade-off between performance ideals and commercial availability. When possible, battery selection and sizing should be coordinated with facility or equipment designing in relation to the charge and discharge electrical parameters, battery space, temperature environment, and ventilation for optimizing system performance. Battery selection and sizing can be accomplished using the procedures given herein and results compared with recommendations from manufacturers.

17. INITIAL PROCESS. When equipment or facility electric power needs have been defined, it should be determined if a battery power source is applicable. The guidance provided in the latest edition of the Electrical Power Policy, Order 6030.20, and Power Policy Implementation of National Airspace System, Order 6950.2, should be applied in the determination of facility requirements. If the equipment or facility cannot tolerate an unscheduled power loss, or requires high reliability or portability, battery power as either the primary or backup source is probably necessary. Basic to these considerations are policy considerations and an initial value analysis dependent on the application needs. If, after initial value analysis, it has been determined that secondary batteries are needed, selection of the battery may begin. In the most difficult case, a new facility or equipment has been or is being designed and will need secondary batteries. Selection will include determining if the application environment is suitable for batteries or needs modification and what electrochemistry to use, in addition to determining battery parameters.

18. <u>DATA SHEET</u>. Figure 3-1, The Facility Battery Selection Data Sheet, is intended as a working paper to use in collecting information about the battery application. Completion of the data sheet should be as accurate as possible, because it provides basic information for selecting and applying the battery in the system. The data sheet should be completed prior to or as the first step in using the flow-chart battery selection procedures. A discussion of entry information items follows the data sheet.

a. <u>Selecting Office</u>. This is the office code or identification of the person filling out the data sheet.

b. <u>Where Battery To Be Used (Facility/Equipment)</u>. This identifies the intended operational site of the battery, eg., HIGH ALTITUDE VORTAC, INDIANAPOLIS, INDIANA or HIGH ALTITUDE VORTAC, CONTINENTAL U.S. or All Maintenance Facilities, AN/XYC PORTABLE DIGITAL VOLTMETERS. The description should always include the equipment designation and type of facility. If the battery will be used in only one specific geographic location, that location may be included.

c. <u>Application or Use</u> of the Battery to be Selected. The intended application or use of the battery will lead to determination of battery type. Data entry should include a description of the intended application or use in general terms for mobility (stationary, mobile, man portable, other terms), using equipment (relays, forklift, etc.), charging scheme (recharge and float, equalizing recharge and stand, automotive regulated, solar, wind generated, other terms), and discharging purpose (engine starting, emergency lighting, motive power, normal primary operating power, other terms).

d. <u>Scheduled maintenance interval</u>. List the interval at which maintenance operations, including battery maintenance, will be performed (six months, no scheduled maintenance planned, etc.).

e. <u>Maintainability considerations</u>. Other maintainability considerations to be listed include whether or not battery maintenance such as voltage measurements or water level measurements or water addition can be accomplished with the system operating, whether or not special provisions such as removal of the battery from the equipment are necessary to test battery capacity, and whether or not battery performance is monitored remotely.

f. <u>Special requirements</u> includes requirements for all-position capability, special chemical compatibility, connection of a gas collection manifold to battery vents, or other battery physical capabilities not generally available.

FIGURE 3-1. BATTERY FACILITY DATA SHEET

FACILITY BATTERY SELECTION
DATA SHEET

Date ____________

Selecting Office ______________________________________

Where Battery to be used (Facility/Equipment)

____

____

Describe application or Use of Battery to be Selected

____

____

Scheduled Maintenance Interval ________________________

Maintainability Considerations ________________________

____

Special Requirements (All-Position Use) (Chemical

Compatibility) (Gassing Manifold) (etc) _______________

____

____

____

Remarks ____

____

____

FIGURE 3-1. BATTERY FACILITY DATA SHEET
(Continued)

FACILITY BATTERY SELECTION DATA SHEET

Facility Application Environments (Operational Battery Ambients)

Minimum Expected Temperature ______ °F Duration _____

Maximum Expected Temperature ______ °F Duration _____

Normal Expected Temperature ______ °F Duration _____

Describe Unusual Conditions (Shock) (Vibration) (Rain)

(Sunlight) (Altitude) (Dust) (etc.) ____________________

____

____

Battery Discharge Load Profile Into Equipment

Maximum Voltage Tolerated __________________ Volts

Lowest Voltage for Required Performance _____ Volts

Maximum Current (inrush, spikes) ____________ Amps

Normal Operating Current __________________ Amps

Complex Load Considerations (see Appendix _____)

____

____

Discharge Duration ______________________________

Maximum Calculated Ampere-Hours Capacity (Include any

design safety margins) _______________ Ampere-Hours

Anticipated Frequency of Deep (>75%) Discharge _______%

FIGURE 3-1 BATTERY FACILITY DATA SHEET
(Continued)

FACILITY BATTERY SELECTION DATA SHEET

Charge Characteristics Available

Charger power from: (Commercial line, renewable energy, etc.) ______________________

When is Recharge Started ______________________

Time Available for Recharge __________ Hours

Maximum Voltage to Battery ________ Volts

Maximum Current to Battery ________ Amps

Method of Recharge (Constant Potential)

(Constant Current) (Hybrid Description) (Pulse Charging)

____

Miscellaneous/Other ______________________

____

____

____

g. A remarks section is included to use for pertinent notes or comments.

h. The facility application environments include the expected temperature values, durations, and unusual environments.

(1) The expected temperature values are the expected ambients at the battery location. The durations may be expressed as a cumulative percentage of a calendar year and may include a daily (or other) duration limit for continuous exposure. Temperature expectations may be determined from climatic charts, facility criteria, or actual measurements.

(2) Unusual environmental conditions to be listed include expected shock or vibration (describe levels, other known

parameters), unprotected battery exposure to rain, direct sunlight, or chemical dusts, altitudes greater than 10,000 feet, etc.

(3) Ventilation that is available shall be described. The type of ventilation, i.e., separate ventilation fans, fresh make up air as part of the heating and cooling system or special ventilation manifolds. The quantity of ventilation air in cubic feet per minute if available. The amount of natural infiltration due to the type of structure, i.e., old structure or new well insulated and sealed structure.

i. Under the battery discharge load profile into equipment, a description of the battery discharge is developed.

(1) Maximum voltage tolerated is the maximum voltage value from the battery that the equipment can tolerate without equipment damage occurring. If this value differs from the maximum value for required equipment operation (performance), both values should be noted.

(2) Lowest voltage for required performance is the lowest voltage value from the battery that the equipment can use to provide required performance.

(3) Maximum current (inrush, spikes) is the highest current value that the equipment will require from the battery.

(4) Normal operating current is the continuous, steady state, or average current that the battery will be expected to provide to the equipment.

(5) Complex load considerations, described in appendix 1, are applicable for capacity determination in cases involving non-uniform or irregular discharge currents. The complex load description should be summarized in the space provided. If the load profile is complex--generally speaking, not a fixed resistance load or constant current load--the exact load profile definition (graph or equation) may be required for purposes of rate and capacity determinations.

(6) Discharge duration is the time (total, uninterrupted) in hours that the battery is required to provide power to the equipment. If there are no means such as voltage cutoff relay or timer within the equipment to automatically stop the discharge, and manual termination of the discharge might not be accomplished, then the battery might be over-discharged to as low as zero volts. This possibility of over discharging to zero volts should be included, along with the planned discharge duration.

(7) The maximum ampere-hour capacity, including any design safety margin in accordance with current FAA policy or

circumstances should be calculated and entered on the appropriate blank. It should noted that this value is uncorrected for temperature, rate, or other variations. If capacity is being specified for automotive batteries in terms of seconds of cold cranking time, rate and rating temperature should also be specified along with reserve capacity. The data sheet term AMPERE-HOURS should be marked out and the appropriate unit terms inserted for automotive batteries.

(8) The anticipated frequency of discharging to greater than 75 percent of calculated capacity should be entered in the appropriate space, expressing the frequency as a percentage of the total number of cycles that the battery will experience. For Type VI renewable energy storage batteries, the total number per year of anticipated occurrences of discharging more than 75 percent should be given.

j. Charge characteristics, all available details of charger performance are entered. If the charger parameters have not been defined because the charger has not been selected, then so note and change the data sheet sub-heading to charge characteristics required.

(1) The source of power to the battery charger should be entered in the appropriate blank.

(2) The question, WHEN IS RECHARGE STARTED? should be answered with, when engine starts, when commercial power is available, or other appropriate description.

Note: If delay of the recharge for more than 2 days is anticipated, this fact must be included.

(3) Time available for recharge in hours should be listed. Current FAA practice is that the time for recharging shall be greater than or equal to twice the discharge time, but in no case greater than 24 hours, according to the formula: $(2 \bullet \text{discharge duration}) \leq (\text{recharge duration}) < (24 \text{ hours})$.

(4) The maximum voltage to battery is the highest voltage that will be available to the battery from the charger. If the charger has 2 voltage steps such as for recharging at a low rate, followed by equalize charging or for equalizing recharge followed by float, both voltage values should be listed. If the charger has an adjustable voltage range, the range should be listed.

(5) The maximum current to battery is the highest current that the charger can deliver to the battery. If the charger has different current capabilities, the capabilities should be described as were the voltage values. Generally, the maximum charging current available should not exceed the maximum discharge current required. If the charger will be providing

operating power to the equipment at the same time it is recharging the battery, the maximum charging current available should not exceed twice the maximum battery discharge current. If the charging method is by constant current (see next entry), the current should result in replacement of 110 percent to 125 percent of the battery capacity (greater than 100 percent due to battery charge efficiency losses) in the time allowed for recharging. For recharging by the constant current method, actual battery charge efficiency must be determined, as well as the amount of overcharge that the battery can withstand without damage or hazardous release of stibine or arsine gases (from lead-acid batteries containing antimony or arsenic).

(6) The intended method of recharge should be described in the appropriate space. The most common recharge method for lead acid batteries is a one-or two-step constant potential recharge with a current limit that is low enough to prevent battery damage but high enough to allow complete recharging well within the allowable time. Nickel-cadmium-alkaline batteries are typically recharged by the constant current method.

k. Miscellaneous/other allows recording of pertinent comments or additional information at the discretion of the person filling out the data sheet.

19. NEW (ORIGINAL) BATTERY SELECTION.

a. Step 1. Collect D.C. Power Requirements. Selection of new (original) secondary batteries begins with collection and review of D.C. power requirements and facility details, including environments. Complete the Facility Battery Selection Data Sheet previously discussed to initiate the selection process. The selection process will continue with determination of battery type, class, style, capacity, environment, number of cells and voltage, charging requirements, maintainability, and remaining parameters for specification. In the end, availability, cost and satisfaction of requirements should be considered to determine realism. Value analysis may be necessary, if electrochemistry has not yet been selected.

b. Step 2. Select Battery Type. The type (FAA nomenclature) of battery describes the intended application in FAA facilities or equipment. Battery design and construction is influenced by intended use or application. A brief discussion of the relationships between type and typical applications follows, with a more detailed discussion contained under the applicability paragraph in Chapter 2. To select battery type, determine from the listed applications the one that best fits the particular need and specify the corresponding type number (roman numeral).

(1) Type I batteries are designed to be maintained on standby on continuous float charge with occasional discharge into

loads such as uninterruptable power supplies, switchgear, or communications equipment.

(2) Type II and Type III batteries are designed to provide high currents for short durations to engine cranking (starter) motors, followed immediately by recharging. Type II batteries are used with stationary engines. Selection of capacity of Type II batteries is facilitated by referring to engine start battery table, table 3-4. Type III batteries are used with motor vehicles and are smaller and more resistant to vibration than type II batteries. Descriptions of the configurations of currently manufactured Type III batteries for automotive applications are contained in Society of Automotive Engineers Specification J537.

(3) Type IV batteries are designed for intermittent discharging at moderate power levels (electric motor loads) with extended stand time (days or weeks) in various states of discharge. Type IV batteries are used to provide motive energy in electric forklifts, transporters, and electric vehicles.

(4) Type V batteries are normally of a sealed design, used for low power discharging in portable test equipment or emergency lights, and are normally recharged within 2 days after use.

(5) Type VI batteries are designed for cycle use at various depths of discharge and low to moderate power levels. A significant portion of the cycle recharges will be incomplete, such cycling being typical of solar power source or wind power source applications.

c. Step 3. Determine Maintenance Interval. The class (FAA nomenclature) of battery describes the maintainability of the battery. To specify class, determine from the listed maintenance intervals the class that fits the particular application, considering current FAA maintenance philosophy and maintenance requirements of collocated equipment, the suitability of the battery installation for accomplishing maintenance, and the different amounts of work (maintenance operations) needed by the different classes. Then specify the corresponding class number (arabic numeral) see table 3-1. Additional discussion of typical associations between class and type is contained under the applicability paragraph in chapter 2. The relationship between class and maintainability is described below.

(1) Class 1 (FAA nomenclature) regular (high) maintenance batteries may require distilled water additions at six month intervals to restore cell electrolyte levels. At 1-year intervals, cell voltage and the electrolyte specific gravity should be measured, equalize charging should be performed, and battery terminals should be cleaned, treated with corrosion preventative, and retorqued. Note, that some battery charging methods auto-

matically accomplish an equalizing recharge after every discharge or on a daily basis through use of 2-step charging, high rate time controlled charging, or daily boost charging controlled by a timer or voltage sensitive relay. All Class 1 batteries should be given an annual equalizing charge to achieve or verify the fully charged state wherein the cell voltages are properly balanced within the battery and, for lead acid batteries, that the electrolyte has the proper specific gravity without tending to increase in value as the equalize charge is continued. (If the specific gravity of lead-acid batteries tended to increase, the electrolyte may have been stratified, plate sulfation may be decreasing, or significant water consumption due to electrolysis may be occurring. If the electrolyte specific gravity remains steadily below the proper value, excess water addition may have ocurred or sulfuric acid may have been lost during specific gravity measurements or through venting aerosol.) Class 1 batteries should be specified when FAA policy permits that level of maintainability, the installation is suitable for it, and the batteries may experience frequent deep discharging or abusive conditions.

(2) Class 2 (FAA nomenclature) low maintenance batteries may require water additions at one-year intervals to restore cell electrolyte levels. Typically, manufacturers recommend against high rate equalize charging of low-maintenance batteries. Automatic equalizing chargers should have lower voltage limits, to provide lower rate equalizing. A typical lower rate equalize charge cell voltage limit for lead-acid batteries would be in the range of 2.3 to 2.4 volts as opposed to 2.4 to 2.7 volts for high rate equalizing. Class 2 should be specified when FAA policy permits or requires that level of maintainability, the installation is suitable for it, and the batteries will not experience frequent deep discharging or abusive conditions.

(3) Class 3 (FAA nomenclature) sealed, no-maintenance batteries simply require no maintenance. Because these batteries are sealed, there are generally no access provisions allowing water addition. Sealed batteries may be damaged or destroyed by extensive overcharging. Typically, Class 3 batteries require more precise control of charging parameters, are slightly more expensive to buy, and may experience shorter life times. Class 3 should be specified when FAA policy and the installation permits or requires that level of maintainability and suitable batteries are available.

d. Step 4. Special Requirements. The style (FAA nomenclature) of the battery basically describes the sensitivity of the battery to being tilted more than 45 degrees or inverted. If, during wet storage or use, it is necessary that the battery be operated or positioned inverted or more than 45 degrees from the normal upright position, Style B must be specified. Otherwise, Style A may be specified. Additional discussion of

TABLE 3-1. MAINTENANCE INTERVAL

	Class 1	Class 2	Class 3
6 Months	X		
Annual	X	X	
No Maint.			X

typical associations between style and type is contained under the applicability paragraph in Chapter 2. The relationship between style and position during storage and use is discussed below.

(1) Style A (FAA nomenclature) batteries contain free electrolyte or are orientation or attitude sensitive in some manner. When the electrolyte is free to move about within the cell, electrolyte stratification may occur in stationary cells. In portable or mobile batteries with free electrolyte cells, hydraulic washing action may erode active materials from the plate surfaces or allow shedded, loose particles to accumulate into electrical paths between plates of opposite polarity, causing cell shorts. Style A batteries may spill electrolyte when they are tilted too far from their normal upright position. Or, when gassing during overcharge, electrolyte may be forced from inverted Style A cells, due to internal pressure buildup. During operation, Style A battery performance may change if the battery is tilted such that some plate surfaces are not completely covered by electrolyte. Style A should be specified only when the battery is to remain in its normal upright position. Commercial batteries can generally be tilted up to 45 degrees from the normal upright position without ill effects, but, without invoking this specific requirement, there is no guaranteed standard. This specific requirement of 45 degrees tilt capability is included in the FAA battery specifications. Style A batteries are more tolerant of overcharge than Style B batteries, because water can be replaced in the electrolyte during maintenance for Class 1 and Class 2. For Class 3, Style A batteries, the cells generally contain hydrogen and oxygen recombination means or excess electrolyte to allow lower rate equalize charging. Style A battery cells are available in many sizes and dominate the larger sizes.

(2) Style B (FAA nomenclature) batteries are not orientation or altitude sensitive, meaning they can be used in any position, including inverted, without variation in perform-

ance. Additionally, the electrolyte in Style B batteries is non-spillable, being constrained in a spongy mat or immobilized in the form of a paste or jelly. Because the electrolyte is constrained in the area of the cell plate surfaces, the battery may be charged and discharged in any position, and the electrolyte won't spill out when the Style B battery is inverted. Style B can only be applied to Class 3 batteries, because water cannot be added to the constrained electrolyte. Due to the constrained electrolyte, Style B batteries are sensitive to significant overcharging, requiring close control of the charging parameters. However, for some Style B battery designs, freezing in the discharged state will not result in physical damage (limited data available). Style B can only be applied to Class 3 batteries and must be specified when the battery may be operated or positioned more than 45 degrees from the normal upright position (or inverted). Style B batteries are mostly available in small or medium sizes, although some larger sizes are becoming available.

e. Step 5. Determine if environmental conditioning is required. The battery environment ambient air temperature is the most significant environmental concern, although vibration or shock may be important in certain applications. Because battery operation depends on electrochemical reactions and the temperature affects the rate of these reactions, battery capacity varies directly with the temperature and battery life varies inversely with the temperature.

(1) Ideally, the battery ambient air temperature should be in the range of 74 - 80 degrees fahrenheit throughout its life. If that is not possible, then consideration should be given to minimizing the temperature deviations from the ideal range, or at least to minimizing the rate of temperature changes. Otherwise, the battery will have excess capacity at high temperatures in order to meet the low temperature requirement and will deteriorate faster due to the necessary higher specific gravity. The temperature ranges given in the FAA battery specifications are approximately the maximum capability for the batteries. Short duration excursions beyond the specification low temperature extremes may not be significant, because the battery mass will require some time interval to reach a new ambient temperature. And during low temperature operation, the amount of power lost in overcoming the battery internal resistance will warm the battery to a slight extent. However, at low temperature the battery capacity is significantly reduced and the normal discharge rate appears to the battery to be higher than normal (when expressed in terms of available capacity). Ambient temperature ranges can be changed by heating, cooling, insulating, or locating the battery underground or in a different area of the facility. A heating or cooling source should not cause localized temperature variations among various points within the immediate battery vicinity.

(2) <u>If the battery environment ambient</u> air temperature is expected to exceed 122 degrees fahrenheit, then the ambient air will have to be cooled or insulation provided. If the magnitude and duration of temperature excursions above 122 degrees fahrenheit is limited to a few degrees for a few minutes (less than an hour) and the battery will not generate significant internal heat (from internal power losses), then insulating the battery area may result in a satisfactory ambient temperature. If the temperature excursion above 122 degrees fahrenheit is more than a few degrees or for more than a few minutes, or if, during discharge or charge, the battery temperature rises sufficiently to cause the ambient temperature to exceed 122 degrees fahrenheit, some method of cooling the battery ambient temperature must be provided by the facility. Cooling sufficient to limit the maximum battery ambient temperature to 80 degrees fahrenheit is most desirable, but value analysis may result in a higher temperature. Cooling mechanisms include air conditioning (refrigeration), circulating water bath. The method of limiting the maximum ambient temperature should be determined on a case-by-case basis. The value analysis should take in to consideration the cost of replacing batteries with the reduced life of high temperature verses the cost of cooling the battery environment to a temperature to adequately increase battery life. When the battery temperature range is between 122 and 80 degrees fahrenheit with the mean temperature remains near 80 degrees fahrenheit the majority of the time environmental conditioning in normally not required. These are the factors that must be considered in a value analysis.

(3) <u>Low ambient temperatures</u> reduce available capacity and may result in eventual freezing of the electrolyte. If the capability can be provided, the ambient temperature should be heated to at least 32 degrees fahrenheit. If the temperature is below -20 degrees fahrenheit (for Types II and III) or +5 degrees fahrenheit (for Types I, IV, V, and VI), heat must be provided or nickel-cadmium-alkaline batteries will be used. If the application calls for large stationary batteries that may set discharged for any length of time (Types I, IV, V, VI) or would require the use of a low specific gravity lead-acid battery, a nickel-cadmium-alkaline battery will be selected.

f. <u>Step 6. Select battery chemistry</u>. Time before recharge may be a factor in selecting battery chemistry. Generally, batteries are recharged as soon as discharging has been completed.

(1) <u>Lead-acid batteries</u> are sensitive to standing in a state of complete discharge, as the sulfate formed by discharge tends to crystalize and harden. Once the sulfate crystallizes and hardens, it is very difficult to convert it back to active battery material during charge. Permanent sulfation results in lost battery capacity. Discharged and sulfated lead-acid

batteries will accept very little charging current when recharge is finally attempted. Some success has ocurred during tests by applying a high voltage (up to twice the normal voltage) with a low current limit for a long duration using reduced specific gravity electrolyte.

(2) Nickel-cadmium-alkaline batteries do not require immediate recharging. If it is determined that the batteries will be routinely left standing in the discharged state (75 percent or less charge) for more than two days, nickel-cadmium-alkaline batteries will be used. If standing for as long as 2 or 3 days in the discharged state will rarely (less than once per year) occur, the lead-acid electrochemistry may still be considered.

(3) Sulfation of a lead-acid battery results in varying degrees of permanent battery damage, depending on the length of stand time, actual depth of discharge (percent of active material forming sulfate), constituent ingredients in the active paste materials of the plates, battery temperature, and electrolyte specific gravity (the sulfate crystals tend to be more soluble in very weak sulfuric acid). Because of the many variables, prediction of exact sulfation damage is not possible. If the extent of sulfation is not serious, capacity loss may be temporary, lasting only a few cycles. In considering whether to select lead-acid or nickel-cadmium-alkaline electrochemistry based on time before recharge, 2 days should be considered flexible with the shortest possible delay before recharging being the most desired for lead-acid batteries.

(4) Delay of recharge after partial discharging is routine in some battery applications. Industrial electric transporters (Type IV batteries) are sometimes operated for 2 or 3 months before recharging, if they are used very little (not completely discharging the battery). And Type VI renewable energy storage batteries may experience 1-3 days of delay in recharging several times each year. Some harmful effects of lead-acid battery sulfation are countered by the composition and design of these battery types. Present lead-acid batteries can stand charged for at least 3 months, with many being capable of 6 months charged stand before requiring recharge. The batteries lose capacity due to internal self discharge during open circuit charged stand, but this lost capacity tends to be recoverable by charging.

(5) Selection of electrochemistry, when based solely on delays in recharge, should be accomplished on a case-by-case basis after thorough consideration of all aspects. If it is anticipated that batteries will remain in the discharged state for longer than two days, select nickel-cadmium-alkaline batteries.

g. Step 7. Determine Battery Capacity. Battery capacity is a measure of the battery's capability to provide current above a certain cutoff voltage for a period of time to using equipment. Mathematically, it is the time integral of the discharge current. The actual capacity delivered by the battery is determined by the battery temperature and discharge rate. Lower temperatures and higher discharge rates will reduce the effective capacity of the battery and require selection of batteries with higher rated capacity than what is calculated by load requirements.

(1) If the battery capacity capability is known, the time duration that the battery will operate the equipment can be determined. If the equipment operating time and current requirements are known or selected, then required battery capacity can be determined. Equipment operating time requirements are typically available and provide a starting point for capacity calculation.

(2) The equipment current requirements may or may not be well defined. If only a maximum current requirement or average (normal) current requirement is available, then capacity must be calculated on that basis and refined when more descriptive data is available. A steady, constant current load is the simplest case, capacity being the product of current (in amperes) multiplied by the time that the current exists.

$$\text{Capacity(Ah)} = \text{current(amps)} \times \text{time(hrs)}$$

As variations in the current value are introduced, the calculation of capacity becomes more involved. A graph depicting battery discharge current values (ordinate) with respect to time of occurrence (abscissa) is called a discharge profile. If the discharge profile is geometrically simple, e.g., a ramp slope, a series of rectangular pulses, etc., geometric area formulas can be used to calculate the total area under the discharge profile curve, which is the capacity. If the discharge profile can be described by a mathematical equation, e.g., a sine wave above zero, and exponential, a parabola, etc., the total area or capacity can be determined by mathematical integration. If the discharge profile curve is mathematically complex, it may be desirable to approximate the capacity by breaking up the discharge profile into small sections, calculating the area of a regular geometric figure (rectangle) that approximates the actual area of the section under the curve, and adding the section areas together to arrive at approximate capacity. (See appendix 1 for complex load calculations.)

(3) Because temperature affects the current needs of some equipment, noticeably engine starters which have to crank cold engines containing high viscosity lubricants or electrical motors driving hydraulic pumps, the capacity needed by the equipment at lowest operating temperature, normal operating

temperature, and highest operating temperature must be determined and compared. The available capacity from the battery must be able to meet the greatest of the needs determined. At this time, any design safety capacity margins not included previously should be included and added to the capacity values at lowest, normal, and highest operating temperature. If the capacity needs increase with increasing temperature or are greatest at normal operating temperature, then the values must be corrected to a standard temperature. In this case the capacity value that will determine battery size is the uncorrected value that results in the greatest corrected value. See chapter 2 for temperature effects on battery capacity and determine temperature correction factors (capacities are typically corrected to 77 degrees fahrenheit). If the capacity needs increase with decreasing temperature or remain the same, then the capacity value that will determine battery size is simply the value at lowest temperature. This value may then be corrected to 77 degrees fahrenheit for comparing with manufactures literature or proposals.

(4) Having determined capacity, the various aspects of rate can be determined. Discussion of ways to describe the discharge rate is contained under the battery ratings paragraph in chapter 2. In the simplest case, the discharge profile is a constant current load that discharges the battery in an integral number of hours, allowing easy determination of C-rate or hour rate (see chapter 2). For non-integral hours, it may be more desirable to specify the actual current. If an hour rate is desired, determine the exact hour rate, round down to the lower integer hour rate, and correct the capacity value for rate variation. In cases of a variable or complex discharge current profile, the discharge rate description selected should be the mean or median rate (whichever is more descriptive for the particular discharge profile), along with maximum and minimum values. For a discharge profile involving high peak currents (spikes or pulses), the time of occurrence relative to the total discharge duration (beginning or middle versus end) may be significant in determining needed battery capacity. If the battery must have the capability to support a sharp increase in discharge rate (current) near or at the end of the capacity discharge, then the total capacity required will be the sum of the actual ampere-hours required by the discharge profile plus the excess ampere-hours capacity necessary to keep the battery voltage from dropping below the cutoff value when the high current demand occurs. Since in this event, almost the total ampere-hours actually required by the discharge profile have already been removed from the battery, the actual ampere-hours required by the discharge profile may be considered to have all been removed at the highest rate. The capacity value of the discharge profile, which is now considered to have been removed at the highest rate, must be corrected to the hour rate, mean or

median rate selected above for the battery (see chapter 2 for discussion of capacity corrections for rate). This results in an excess ampere-hour capacity above the quantity required strictly by the discharge profile at the lower rate selected initially. An indication of this capacity change is given in table 3-2 and table 3-3 for lead-acid and nickel-cadmium-alkaline respectively. Temperature correction of capacity should be accomplished after rate correction.

h. Step 8. Selecting the number of cells and cutoff voltage.

(1) The number of battery cells required is determined by cell electrochemistry and the equipment operating voltage range. If the battery must remain connected to the equipment during charge, the voltage value at completion of charge (including equalizing and float voltages) must be within the equipment operating range. If the battery will not remain connected to the equipment during charge, then only the charged battery open circuit voltage value need be within the equipment operating range. To calculate the number of cells, divide the maximum equipment operating voltage by the maximum charge voltage (or open circuit voltage, whichever is applicable) of a single cell of the desired electrochemistry (see Chapter 2 for voltage values). The resulting quotient should then be rounded down. This is the number of series-connected cells in the battery.

TABLE 3-2. EXAMPLE OF LEAD-ACID LOW RATE STATIONARY BATTERY CAPACITY* VERSUS RATE

DISCHARGE RATE	PERCENT CAPACITY
C/46	157%
C/18	139%
C/10	114%
C/8	100%
C/6	86%
C/5	79%
C/4	71%
C/3	52%
C/2	26%
1C	1%

*NOTE: Capacity to cutoff voltage of 1.75 volts per cell, 77°F ambient, C is the capacity at the 8-hour rate. When high rate (<C/2 applications) batteries are required, different designs should be used that do not conform to this sample table and capacity should be stated in terms of maximum load current for the time required.

TABLE 3-3. EXAMPLE OF NICKEL-CADMIUM-ALKALINE POCKET PLATE CELL CAPACITY* VERSUS RATE

DISCHARGE RATE	PERCENT CAPACITY
10-HOUR	105%
8-HOUR	103%
5-HOUR	100%
3-HOUR	96%
1-HOUR	81%
30-MINUTE	64%
1-MINUTE	5%

*NOTE: Capacity to cutoff voltage of 1.00 volt at 77 degrees fahrenheit ambient. The 5-hour capacity is the baseline or nominal rate.

Batteries are commercially available in standard voltages such as 2 volts, 6 volts, 12 volts, 24 volts, etc. In these batteries the actual voltages vary somewhat from the integral values, but commercial equipment designed for these batteries will accept the variations. In some of the larger systems, primarily stationary systems where around a hundred or more cells may be connected in series, the number of cells becomes flexible and non-standard. For a fixed voltage value, say 225 volts, 100 cells would each be at 2.250 volts (average), 99 cells would average 2.273 volts, 101 cells would average 2.228 volts, and so on. In these non-standard cases, tradeoffs can be made between the total number of series cells and average or individual cell voltages, to benefit one particular electrochemistry or modify the cell voltages at an end point (charge or discharge). The governing requirement is that the battery must be capable of operating within the equipment operating voltage requirements.

(2) Cutoff voltage is the lowest voltage at which the battery current is usable by the equipment. Certain equipment has voltage sensing provisions and capability to turn itself off when a pre-selected voltage value is reached. Other equipment may terminate operation (and battery discharging) at a preset time or duration. And some equipment may remain connected to the battery until it is manually disconnected or turned-of, possibly discharging the battery to zero volts. If it is probable that the battery will be discharged to near zero volts or even below an average cell voltage of less than 0.8 volts per cell (varies with manufacturer), then nickel-cadmium-alkaline electrochemistry should be selected. See chapter 2 for voltage cutoffs for various nickel-cadmium-alkaline battery designs. All battery voltage cutoff calculations must allow for the line voltage drop (due to line resistance) between the battery and the using equipment.

(a) <u>If the equipment has a time-based</u> limit (duration or approximate capacity) for terminating discharge, the cutoff voltage can be approximated by determining the approximate capacity and depth of discharge and correlating these values with the theoretical or experimental cell voltage predicted at that point (capacity or percent) for the selected rate and allow for line voltage drop. Manufacturers' data relating voltages, rates and capacities should be utilized for this correlation.

(b) <u>If the equipment has an automatic</u> cutoff at a preselected voltage, divide the preselected voltage (with allowance for line voltage drop) by the number of cells to determine the cell voltage cutoff. If the cutoff voltage for the equipment is above the voltage at which the battery is rated the effective capacity of the battery will be reduced for the particular application. If this situation occurs batteries with higher rated capacity need to be specified because the complete rated capacity of the battery is not available at the required cutoff voltage. For lead-acid batteries, the individual cell voltage cutoff point below which the cells will experience damage or shorter lifetimes depends on the discharge rate, generally 1.75 volts for low to moderate rates, and from 1.75 volts to as low as 0.8 volts (depending on manufacturer) for moderate to very high rates. Some designs of nickel-cadmium-alkaline cells also have voltage cutoff limits (see Chapter 2).

j. <u>Step 9. Determine battery charger requirements</u>. Charger requirements are determined by the voltage and current requirements of the equipment and the battery. The charger must be capable of returning the battery to a state of full charge within the time allowed. Need for equalizing charge capability depends on the frequency of deep discharging. All chargers should include manual adjustment capability (internal or external) for maximum voltage and current limit capability to provide flexibility to support batteries from various manufacturers. Nickel-cadmium-alkaline battery chargers are typically of the constant current type, one-step or single current value for time limited recharges and two-step recharge (current and float current) for continuous charging. Lead-acid battery chargers are typically constant voltage with a current limit. Lead-acid battery chargers will have dual voltage capability, if the equalize charging capability is included. For all battery chargers, current FAA practice is that the time for recharging shall be greater than or equal to twice the discharge time, but in no case greater than 24 hours according to the formula: $(2*\text{discharge duration}) \leq (\text{recharge duration}) < (24 \text{ hours})$. Current capability should be such that a capacity equal to the capacity discharged divided by the battery charge efficiency is returned to the battery within the time allowed. Efficiency for lead-acid is typically 85 percent and 68 percent for nickel-cadmium-alkaline batteries.

20. DETERMINE BATTERY PARAMETERS.

a. Remaining battery parameters to be determined when using the FAA battery specifications are discussed in the sequence in which they are presented in the specifications. Selection and specifying of detailed battery parameters is necessary for procurement purposes. The general specifications for batteries allow procuring batteries meeting general requirements, but many details must be specified for each application.

(1) Battery Condition (Applicable only to lead-acid batteries). The battery condition, when shipped, is either wet and charged or dry and charged. The desired condition must be determined from storage conditions expected. Battery condition should be dry and charged for long term storage, or wet and charged for immediate operation. Battery are more hazardous in the wet and charged condition, but requires activation before operation when dry and charged. When dry and charged batteries are specified, delivery with or without electrolyte should also be specified, as determined by FAA policy considerations and circumstances at the time. To specify battery condition in the lead-acid (only) specification, specify wet and charged or dry and charged with or without electrolyte (when dry charged), as applicable. Before specifying dry charged condition, determine if the existing charger capabilities can provide suitable activation charging, typically 5 amperes current per 100 ampere hours of capacity.

(2) Battery Dimensions. To specify the battery dimensions, specify the dimensions available for the battery after subtracting any necessary access space for maintenance or connection when in the equipment.

(3) Battery Weight. To specify the battery weight, determine and specify the weight limitations for the wet, charged battery supports, including rack weights when racks are to be delivered with the battery.

(4) Flame Arresters. Determine and specify that flame arresters are not to be included, if there is no reasonable chance for battery gasses to be ignited (such as when a sealed battery, Class 3, is specified). Flame arresting vents are automatically required by the specification, unless otherwise specified. Also specify vent provisions required for connecting to an exhaust manifold, if manifold provisions are included in facility requirements (see chapter 4).

(5) Battery Terminal Configuration. Determine and specify the desired battery terminal configuration. The terminal configuration must include dimensions (shape and size). Terminal locations on the battery should also be specified, although the specification does provide terminal locations when none have been specified. The specification does specify terminal corrosion

protection, terminal resistance, terminal strength and clearances. Terminal configurations and locations may be specified using industry standard numbers such as are available for automotive batteries or by using dimensioned drawings or other description. Any special functioning, such as plug-in, twist-lock, or quick disconnect capability should also be specified. To specify terminal configurations and locations, specify the terminal (positive and negative) dimensions, locations, and special functions (if applicable) by means of drawings, industry standard numbers, or other description.

(6) Battery Handling Provisions. Determine and specify the desired provisions for handling the battery. If no handling provisions are specified, the handling provisions will be as detailed in the specification. To specify battery handling provisions, provide a dimensioned drawing and functional requirements or describe the handling provision design.

(7) Battery Mounting Provisions. Determine and specify the desired provisions for mounting the battery in the equipment or installation. If no mounting provisions are specified, the mounting provisions will be as detailed in the specification. To specify battery mounting provisions, provide a dimensioned drawing and functional requirements or describe the mounting provisions design.

b. Battery Item Level. Determine and specify the battery item level. If no battery item level is specified, the specification does provide the item level for single or multi-cell batteries, as applicable. To specify the battery item level, specify item level (a) Single Cell Battery, (b) Multi-cell Battery, (c) Cells or Cell Packs to be assembled into a Multi-cell Battery after delivery, or (d) Cells or Cell Packs for use as replacement or spares (reserves). (Note: FAA battery specification item level (c) cell or cell packs to be assembled into a multi-cell battery after delivery requires the contractor to provide all labor, hardware, materials, and equipment necessary to set up the battery for operation.) When this item level is specified, the schedule for installation and intended FAA facility location must also be specified, otherwise setup by the contractor should be deleted from the requirements.

(1) Battery Environmental Requirements.

(a) Determine and specify the battery environmental requirements. If no environmental requirements are specified, then the battery environmental requirements will be as detailed in the specification. (See the previous discussion (19e.) for the temperature environment.) The environmental requirements to be specified are the storage conditions, shipping and handling conditions, and operating conditions, including ambient temperatures, ambient relative humidity, altitude, vibration, shock, and any other expected environment (such as salt air, blowing sand and dust, sunlight, fungus, corrosive or other abnormal atmosphere, etc.). Include details as to durations, amounts, rates, application points, etc. The operating functional shock requirement may be deleted for the Type V battery in emergency lighting applications if the battery will not be subjected to shock during operation.

(b) Vibration or shock may be a problem in some application, particularly in aircraft and some vehicle or marine installations. Withstanding vibration or shock requires a more structurally sound battery, with restraints to limit plate motion and to prevent loss of active materials from the plate surfaces. If the vibration or shock environment is severe, consideration should be given to providing vibration or shock isolators for the battery installation. Determine and specify applicable vibration and shock exposure parameters. The vibration and shock requirements given in the FAA battery specifications can be demonstrated by testing the batteries in accordance with other specifications. The shipping and handling vibration test is described in MIL-STD-810d (19 July 1983), Basic Transportation. This test represents shipment by common carrier land transport for 1000 miles. The operational vibration tests are from SAE specification requirements. The shipping and handling shock test is described in MIL-STD-810D (19 July 1983), method 516.3, procedure VI. The Type V battery operational shock test is described in MIL-STD-810D (19 July 1983), method 516.3, procedure I, functional shock. Note: The operating (functional) shock requirement of FAA battery specifications may be deleted for the Type V battery in emergency lighting installations if the battery will not be subjected to shock during operation.

(c) Protection from precipitation and direct sunlight should normally be provided for the battery. The altitude of most ground installations will not exceed 10,000 feet. Determine and specify applicable direct sunlight and precipitation exposure parameters.

(d) Battery Racks. Determine and specify if battery racks are to be included with the batteries and whether or not the racks should have seismic capability. Battery racks are normally required only with Type I UPS batteries under item level (c) cells or cell packs to be assembled into a multi-cell battery after delivery and may be required for Type II batteries under the same item level. To determine if seismic racks are necessary, review chapter 4, Seismic considerations, contained in this order. To specify battery racks, specify if battery racks are to be included with the battery and whether or not the racks are to have seismic (zone 4) capability.

(e) Battery Data. Determine and specify if no data is to be delivered with the batteries. The specification requires that information necessary to prepare and operate the batteries be delivered with the batteries. To specify no data, specify no data required. If other data (such as drawing or performance graphs or tables) is required, describe what data is necessary and specify the requirement in accordance with current procurement procedures for obtaining data.

(f) First Article. Determine and specify if first article specification requirements apply. If first article is required, the contractor must provide test samples and accomplish first article tests. This requirement should normally be reserved for very large quantity procurement, as it is expensive and time consuming. The contractor incurs additional expense for samples and tests, which will impact bid price and schedule. The first article requirement includes components, batteries, and preparation for delivery (battery packages). To specify first article, specify first article is required, and describe any special tests or circumstances.

(g) Quality Assurance Responsibility. Determine and specify who is responsible for accomplishing the quality assurance inspections (tests), if other than the contractor. Also determine and specify what inspection facilities are to be used, if other than those selected by the contractor. Unless otherwise specified, the specification requires that the contractor be responsible for the quality assurance inspections, which may be accomplished in suitable facilities of the contractor's choice. To specify otherwise, specify who, other than the contractor, is responsible for accomplishing the quality assurance inspections and what facilities are to be used.

(h) Responsibility For Supplying Test Equipment. Determine and specify who is responsible for supplying the necessary test equipment. Unless otherwise specified, the specification requires that the contractor supply all test equipment necessary for the specification tests. To specify who is responsible for supplying the test equipment, specify the test equipment provider and what equipment will be provided, including a schedule.

(i) Preparation For Delivery. To specify preparation for delivery, provide the information required by paragraph 6.3(i) of the battery specification (levels of preservation, packaging, and packing required) as well as the information required by paragraph 6.2 of MIL-E-17555.

21. FLOW CHART SELECTION OF NEW (ORIGINAL) BATTERIES. As a brief summery of guidance to battery selection, the following battery selection (next page) flow chart and Appendix 3, Battery Selection and Sizing Example is presented. This flow chart is applied for selecting new (original) batteries.

FIGURE 3-2. BATTERY SELECTION FLOW CHART

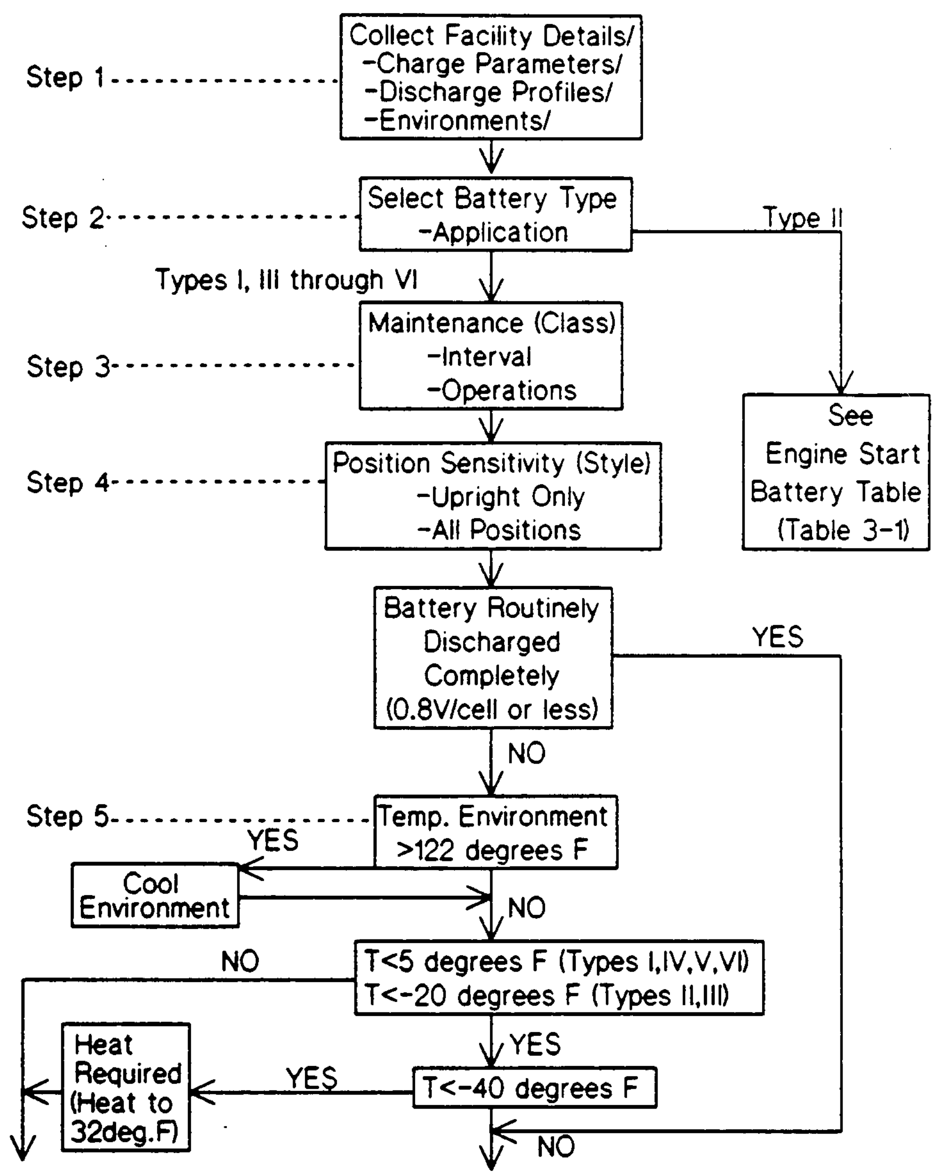
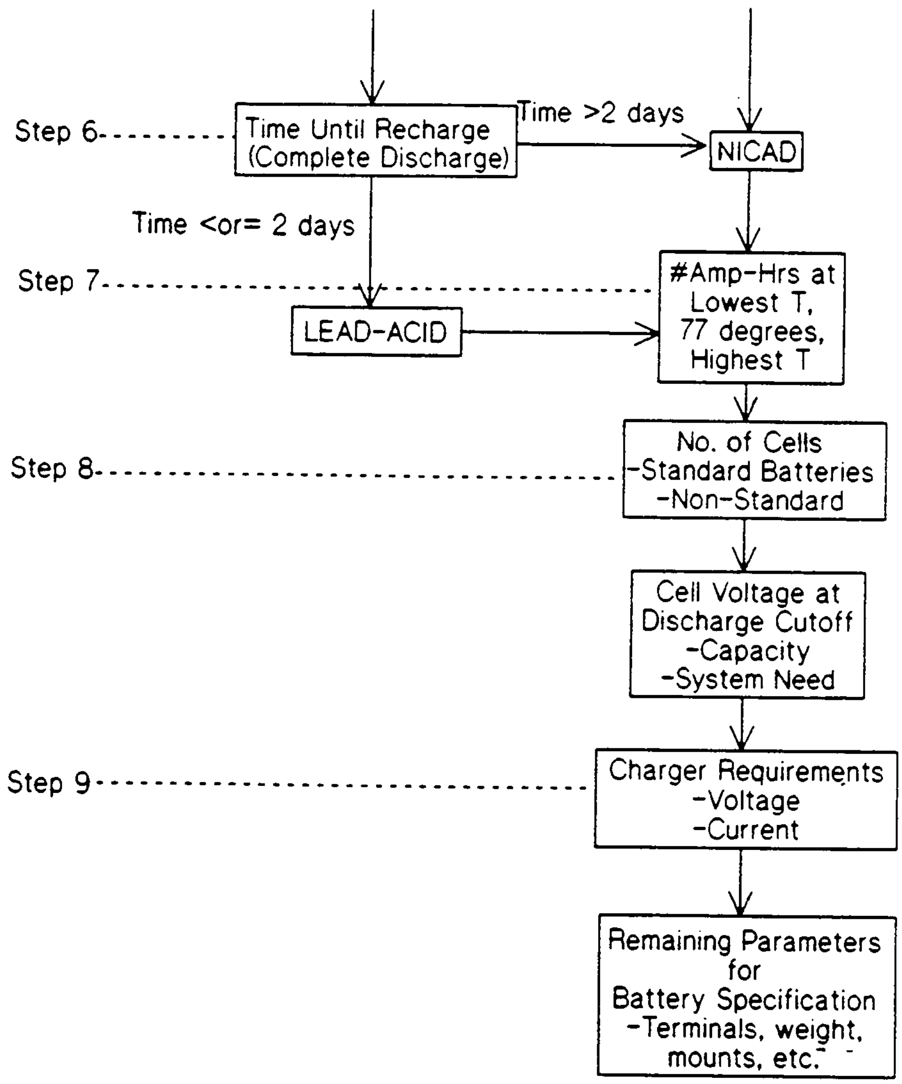


FIGURE 3-2. BATTERY SELECTION FLOW CHART
(Continued)



SECTION 2. REPLACEMENT BATTERIES

22. REPLACEMENT BATTERIES. Battery replacement should be accomplished when the battery no longer provides required capacity or performance (with the charger functioning properly), when the battery life has exceeded its design value, or at the convenience of scheduling and funding availability when the above factors are expected to occur shortly. Multicell batteries that are not designed with replaceable cells should be

TABLE 3-4. REPLACEMENT BATTERY DATA FOR STATIONARY ENGINE GENERATORS

ENGINE kW	BATTERY VOLTAGE	WATT-HOURS (8 Hour Rate)
5	32	2020
7.5	32	2660
10	32	3200
15	32	4100
20	32	4800
30	32	6000
50	32	7700
60	32	8500
100	32	10000
125	32	11000
150	32	12000
175	32	13000
200	32	13750
250	32	14750
300	32	15500

NOTE: To compute battery capacity in ampere-hours (for a particular size generator), divide the WATT-HOURS column by the BATTERY VOLTAGE column. Use nearest size available.

replaced as a complete battery preferably of the same part number. In all replacements, electrochemistry, type, class and style should remain the same. The replacement battery should not have less capacity than the original battery, but may have more capacity within the limits of charger capability, equipment need, and size limits. Other battery parameters should generally remain the same. For batteries having replaceable cells, selecting between replacement of cells or entire batteries involves several factors as discussed below.

a. During the lifetime of a battery (that is assembled at the site using cells or cell packs), one or more cells or units may fail. If a failure occurs in the early part of the expected life, the manufacturer should be contacted for a replacement since the cell may be in full or partial warranty. If a failure occurs during the latter part of the expected lifetime, replacement is more subjective. First, it may be possible that the battery can meet the load requirements with one or several cells missing. Second, it may be more economical to replace the entire battery at one time rather than replace individual cells as they fail since, in the later case, the total labor involved in replacing individual cells or units piecemeal may be more than if the entire battery was replaced at one time. Also, cells purchased later may cost more due to inflation. If a required cell or cell pack or acceptable substitute cannot be found, the entire battery (complete electrical unit, battery bank) will have to be replaced. Individual cells or cell packs are generally not repairable. Final determination as to replacing individual cells or the complete battery will depend on technical and administrative factors existing at the time.

(1) Replacement of individual cells or units should be accomplished with cells or units of the same part number or same type, class and style and preferably from the same manufacturer. There are several reasons for this. First, batteries (especially stationary) are usually purchased as a set of cells together with battery rack and all interconnecting hardware. Except for automotive batteries, there is little, if any, semblance in form factors between manufacturers. Thus, if a different part number, or type, class, or style of cell (or battery) is selected, having differences in height and/or width, length, or terminals, some of the interconnecting hardware may have to be discarded and jumpers or interconnecting cables fabricated. Additionally, the replacement cell or unit may not fit the existing rack.

(2) In addition to physical differences between different types of cells, there are electrical differences. The effect of these differences will depend upon the type of battery (stationary lead-antimony versus stationary lead-calcium) and operating conditions. For example, if lead-calcium stationary cells were to be used to replace lead-antimony stationary cells, the lead-calcium stationary cells would not be maintained fully charged, unless the float voltage was increased, since the nominal float voltage for lead-calcium stationary cells ranges from 2.17 to 2.38 volts/cell (depending on the specific gravity) and for the lead-antimony stationary cells, it ranges from 2.15 to 2.17 volts/cell with a nominal specific gravity of 1.210. If the nominal system voltage range was such that the equipment could withstand the higher voltage required, there would be no problem in adjusting the voltage upward. However, if the cells or a group of cells were only a part of the total battery then problems could arise. For example to keep the lead-calcium stationary cells fully charged, the float voltage may have to be raised to a level that the equipment could not withstand. Even if the equipment were able to withstand the higher battery float

voltage, the net results would be that other stationary cells would be constantly overcharged. This overcharging would require more frequent additions of water to maintain the proper electrolyte level. Additionally, the overcharging could accelerate plate grid corrosion. This could cause an unacceptable increase in maintenance visits to a facility to maintain it in operation. Substitutions such as this should only be done on an emergency basis. It should be noted that the use of automotive-type batteries for emergency systems is specifically prohibited by the National Electric Code of 1987 (Article 700-12(a)).

(3) Even the partial replacement with units of the same type, class and style but different part number, or the same part number but different age (older cells versus new cells) can present some problems, although the problems may not be as severe. For example, on discharge, two different part numbers, but same type, class and style stationary cells, or an older and a newer cell having the same part number, will experience different depths of discharge because of slight differences in capacity. The degree of difference will depend upon the relative capacities and the quantity of ampere-hours removed. During recharge, some cells will have to be overcharged in order to recharge all cells properly (because charging is accomplished in series and all cells receive the same quantity of ampere-hours). This may result in cell voltage imbalances within the battery, as well as higher water consumption and grid corrosion in the cells that are overcharged the most. If an exact replacement cannot be found, then the next best replacement based on capacity and float and equalizing voltages should be selected.

b. Battery or cell replacements should generally be of the same part number, type, class, and style as the replaced battery or cells. Replacement of the entire battery should be accomplished with a battery of the same part number or, at least, of the same type, class, style, and performance parameters. Priority should be given to the electrical parameters as the mechanical configuration of the facility is more easily and readily modified in the field than are the electrical characteristics of FAA facilities. The replacement battery or cell should not have a depth of discharge capability (and capacity) less than that of the battery being replaced. If a desired part number battery is no longer available and an equivalent substitute has not been identified, then selecting a replacement will require using new (original) battery selection procedures.

CHAPTER 4. BATTERY FACILITY DESIGN

23. BATTERY FACILITIES. The battery facility is the battery plus the associated structures and provisions necessary to enable use of the battery in or with equipment. Guidance contained in this chapter provides engineering and design considerations, exclusive of electrical details, for applying a battery in a system. The following paragraphs discuss in general terms the battery location, area ventilation, temperature environment, weight support, seismic considerations, and safety.

24. ROOMS, COMPARTMENTS, PLATFORMS. General requirements for the location and installation of batteries are similar for lead-acid and nickel-cadmium-alkaline electrochemistries. The battery should be located close to the equipment it powers, in order to minimize conductor resistive power losses. For reasons of personnel safety, operational security, and prevention of accidental battery damage, the battery should be in an area of controlled access. Batteries may be installed in a room separate from the electronic equipment, if the batteries are large or of high voltage and the equipment is attended by several personnel. Or, batteries may be placed on a platform or in a compartment within the equipment, for reasons of portability, limited access, or proximity to using systems. The batteries should be located out of direct sunlight, away form heat sources, and protected from rain, snow, dust and chemical contamination. Battery safety aspects include considerations of chemical interactions, electrical (magnitude of charge and discharge currents and voltages), evolved explosive or toxic gasses and corrosive vapor ventilation, and access space for installation and maintenance. For longest battery life and best performance, the battery environment should be temperature controlled. Additionally, battery facility design must include provisions to provide adequate stable support for the battery weight, even under earthquake-induced motion, and allowance for battery momentum in mobile installations. Where mechanical vibration is severe, shock or vibration isolation will be necessary.

25. BATTERY FACILITY VENTILATION.

a. All secondary cells with water-based electrolyte can produce outgassing of hydrogen and oxygen by electrolysis of water. This outgassing occurs mainly during float operation (at gassing voltages) and during equalize charging for lead-acid and nickel-cadmium-alkaline batteries. Electrolysis of water can occur in sealed cells and vented cells. For this reason, all sealed cells should include provisions to vent gasses before pressure buildup would result in cell fragmentation. Some sealed cells include catalytic provisions for recombination of hydrogen and oxygen into water. Where practical, consideration should be given to the use of hydrogen detectors to alert to the presence of impinging unsafe levels.

(1) Outgassing can occur on discharge when cells are connected in series. If, during discharge, one or more cells are depleted (discharged to zero volts), due to lower capacity than the other cells in a series string, the higher capacity cells can drive the lower capacity cells into reversal (reversed polarity charging). If this reversal is extensive, the cell will outgas.

(2) Some outgassing can occur when the battery is on float charge if the charging voltage is too high. Each ampere-hour of overcharge (current that does not go into actually charging a cell to its full capacity) will produce about 0.016 cubic foot of hydrogen gas, H_2. Ventilation must be provided to prevent the hydrogen from building up to one percent concentration by volume of room air at any time to comply with the Occupational Safety and Health Act (OSHA). At approximately 4 percent concentration, hydrogen presents an explosive mixture with room air, which can be ignited by a spark.

b. It is generally difficult to calculate the amount of hydrogen given off during equalize and float charging because of the effects of battery age (deterioration) and plate component material on float current. If the float current is known, then the rate of gas generation can be calculated using a figure of 0.000269 cubic feet of hydrogen gas produced by 1 cell in 1 minute per ampere of float current. A convenient formula for calculating the amount of hydrogen (H_2) evolved from a battery (one series string) is:

Volume of H_2 in ft^3 =
(0.016)(ampere-hours of overcharge)(number of cells in series string)

(0.000269 cu ft of H_2)(60 minutes/hour) =
(0.0159 cu. ft. of H_2 / Hour)
{Average for all lead acid batteries}

c. The rate of evolution is simply the volume of H_2 divided by the overcharge time or:

$H_2(ft^3/hr)$ =

(.016)(ampere-hours of overcharge)(Number of cells in series string) divided by Time in hours (duration in hours of overcharge)

d. The amount of ventilation required to keep the hydrogen to a maximum concentration of 1 percent during recharge is:

Ventilation (ft^3/hr) = H_2 (ft^3/hr) (100)

The above can be rewritten as:

$$\text{Min Ventilation } (ft^3/hr) = \frac{1.6(\text{ampere-hours of overcharge})(\text{number of cells in series string})}{\text{Overcharge Duration in hours}}$$

e. <u>Hydrogen evolution</u> is nominal to non-existent when the battery is on float charge at the proper voltage. Typical float currents at the proper voltages are:

Lead-acid antimony = 0.001-0.035 A/Ah of cell
Nickel-cadmium-alkaline High Rate = 0.003 A/Ah of cell
Nickel-cadmium-alkaline Med. Rate = 0.002 A/Ah of cell
Nickel-cadmium-alkaline Low Rate = 0.001 A/Ah of cell

f. <u>A worst case condition</u> would be for the battery to be fully charged and the charger voltage output to remain in the equalize or high-rate charge mode. Under this condition, the current through the battery is many times higher than the normal float current would be (see preceding sub-paragraph). Thus, it is important to closely control the equalize charge duration, if only to prevent buildup of hydrogen.

g. <u>The ventilation requirements</u> to prevent hydrogen accumulation beyond 1 percent concentration require complete air volume exchanges in a period determined by the room air volume and hydrogen production volume as described in preceding subparagraphs. Rooms which are occupied by personnel may require air volume exchanges at a higher rate, depending on human factors design requirements, such as length of occupation and number of personnel in the facility. This applies to both controlled and uncontrolled environments. Ventilation can be accomplished by simply exhausting the battery room air out-of-doors. Where this is not practical, the battery vents can be connected to an exhaust manifold that releases vented gasses out-of-doors. The volume of air for exhaust may be reduced from room-sized quantities by placing the battery in a closed container and venting the container out-of-doors (along with providing provisions for container make-up air.

h. <u>If the battery room is supplied</u> with conditioned air by a part of a building's general system, the exhaust air should not be returned to the distribution system but directed outside. Hydrogen is lighter than air and, although it disperses rapidly throughout an enclosure, it may initially accumulate in the highest part of the ceiling area. This is where the exhaust vents or exhaust fans should be located.

i. <u>Other battery emissions</u> removed by proper ventilation are aerosol electrolyte and electrolyte vapors, arsine or stibine gasses (from lead-acid batteries with arsenic or antimony in the lead), and gasses or vapors resulting from breakdown of organic or synthetic materials within the battery or battery case.

26. <u>TEMPERATURE ENVIRONMENT</u>. The operating temperature for batteries is the single most important factor affecting the life and electrical capacity of the battery system. The battery space or room should be insulated to minimize temperature extremes or, at least, to minimize the rate of temperature change due to outside causes. A battery location with an ambient temperature at 75 to 77 degrees fahrenheit will result in maximum battery life and full capacity. A higher temperature will result in a reduced service life, and a lower temperature will result in reduced capacity. Operation at temperatures of 60 to 90 degrees fahrenheit will not greatly affect the service life or capacity. Batteries are capable of operating over much wider temperature ranges, but the smaller the range of temperature extremes and the closer to the ideal temperature, the more cost efficient the battery system will be. If any heating provisions can be provided, they should be capable of limiting the lowest temperature to 32 degrees fahrenheit. Ideally, heating provisions should be capable of maintaining a temperature of 74-77 degrees fahrenheit. If cooling provisions can be provided, they should be capable of limiting the highest temperature to 90-95 degrees fahrenheit. Ideally, cooling provisions should be capable of maintaining a temperature of 77-80 degrees fahrenheit. When considering trade-offs, high temperatures shorten battery lifetime, requiring sooner replacement. Low temperatures reduce battery capacity, requiring larger size batteries.

27. <u>WEIGHT SUPPORT</u>. Batteries come in a very wide range of weights (and sizes) from small and light hearing aid and flash light batteries to industrial fork lift and military submarine reserve power batteries. Facility design provisions must include adequate, stable support for these batteries, as well as being capable of withstanding battery momentum changes in mobile installations.

28. <u>SEISMIC CONSIDERATIONS</u>. Some battery facility installations may require the use of seismic racks for supporting the batteries. The necessity for seismic racks is determined from the earthquake-induced acceleration (g-level) requirements for the particular location (zone) or application. These zones are presented on the next page in Figure 4-1, Seismic Zones.

a. <u>The seismic zone maps</u> on the following page, figure 4-2, from the Uniform Building Code may be used as a general guide for determining seismic risk. Specific guidance should be obtained from the applicable state building code. As a precaution against mixing racks designed for different seismic zones when moving racks to a different location, all seismic racks should be specified for zone 4.

FIGURE 4-1. SEISMIC ZONES

ZONE 0 - No damage.

ZONE 1 - Minor damage; distant earthquakes may cause damage to structure with fundamental periods greater than 1.0 second; corresponds to intensities V and VI of the M.M.[1] Scale.

ZONE 2 - Moderate damage; corresponds to intensity VII of the M.M.[1] Scale.

ZONE 3 - Major damage; corresponds to intensity VIII and higher of the M.M.[1] Scale.

ZONE 4 - Those areas within Zone No. 3 determined by the proximity to certain major fault systems.

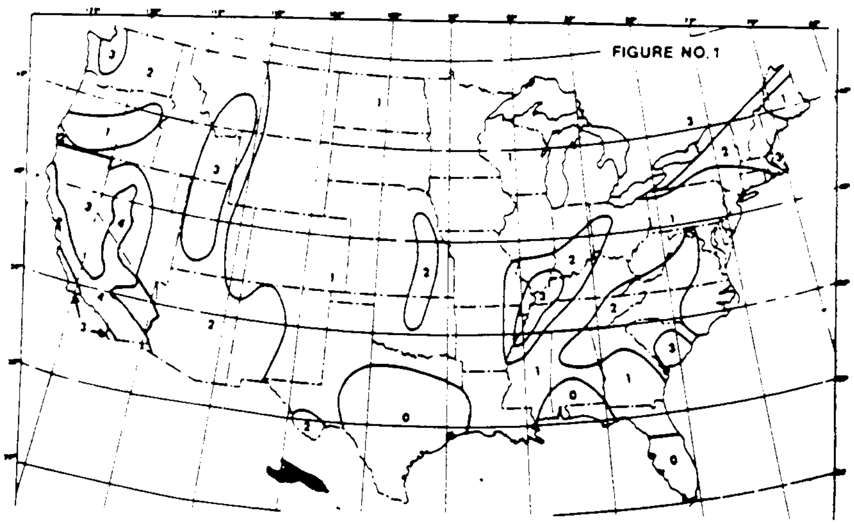
29. SAFETY. - Battery safety considerations encompass chemical, electrical, explosive gas, and access space considerations. A summary of these considerations is provided as the following general safety requirements.

a. Chemical considerations include personnel protective measures requiring splash shields, goggles, showers, and eyewash facilities. Showers will not normally be required unless the main function of the facility or that portion of the facility is to perform maintenance on batteries. When major battery maintenance is being performed at an operational facility portable showers or some other emergency source of water should be made available. Batteries or chemicals should not be mixed with those of opposite reactivity, such as placing lead-acid batteries in proximity with nickel-cadmium-alkaline batteries. Only distilled water or the correct electrolyte should be added to batteries. Saltwater added to sulfuric acid electrolyte will result in massive release of chlorine gas. When diluting concentrated electrolyte with distilled water, concentrated electrolyte should be added slowly to the distilled water -- do not add distilled water to concentrated electrolyte.

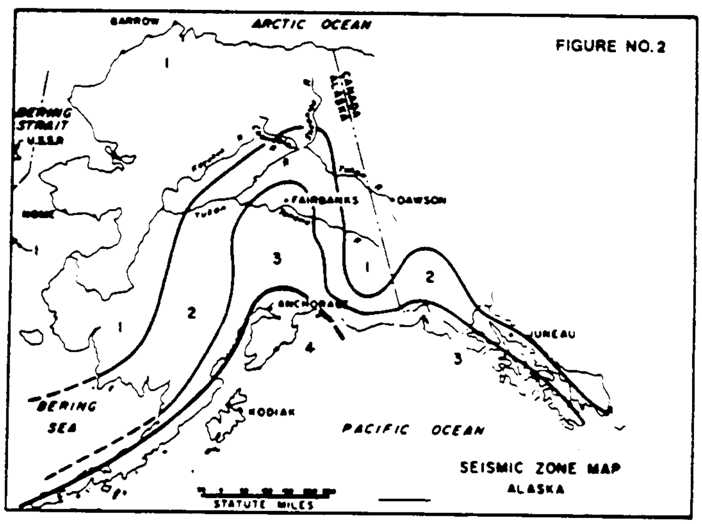
b. Electrical considerations include provision of insulated surfaces (conductors, walkways, tools, and work surfaces). The National Electric Code should be consulted for requirements for posting High voltage warning signs. The high current capability of batteries requires consideration of current interrupters to prevent fires due to over-current or short circuits; arcing protection to prevent ignition of combustibles and explosive gasses; and electromagnetic noise

1/ Modified Mercalli Intensity Scale of 1931

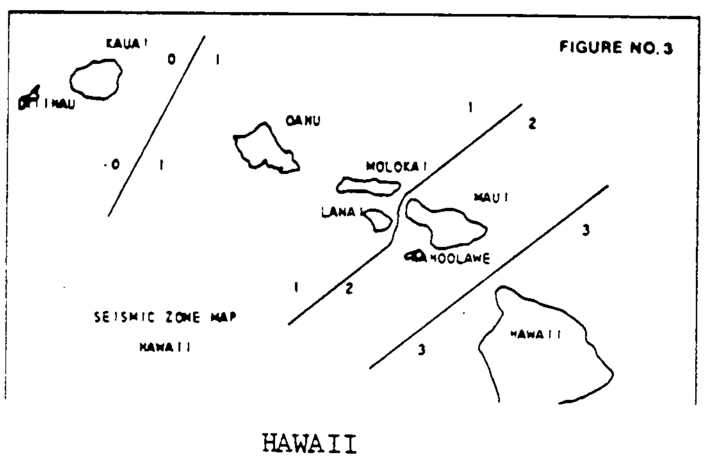
FIGURE 4-2. UNITED STATES SEISMIC ZONES



CONTINENTAL UNITED STATES



ALASKA



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suppression to prevent interference with sensitive electronic equipment. Access space should be sufficient to allow unobstructed battery or cell removal and replacement, personnel movement, and maintenance operations.

c. General Safety Requirements. The safety precautions listed below apply to both lead-acid and nickel-cadmium-alkaline systems. Gelled and low volume electrolyte batteries are somewhat less hazardous than stationary batteries since they are sealed. With all sealed batteries, leakage or spillage of electrolyte is less likely to occur, and the emission of gasses and corrosive fumes is suppressed. However, the hazard possibilities still exist, and caution must continue to be exercised when working with these batteries.

(1) Limit personnel access to the battery room to only those personnel that are familiar with battery installation, charging, maintenance, and safety procedures.

(2) Unobstructed exit from the battery area should be provided.

(3) Smoking or the use of open flames in the battery room should be prohibited. NO SMOKING signs should be posted at the entrance to the battery room.

(4) Protective equipment consisting of an apron, gloves, goggles or face shield with goggles should be worn when batteries are being handled, installed, or maintained.

(5) Only tools with insulated handles should be used to make connections to the battery. Metal tools or other objects should not be placed on top of batteries, since they may cause sparks that could result in an explosion of hydrogen gas in or near the cells. A nonmetallic flashlight with a non-sparking switch is recommended when a flashlight is needed for inspecting batteries.

(6) Rings and wristwatches should be removed before working on batteries in order to prevent shorting of conductors and resulting sparks, shock, or skin burns.

(7) Do not break a current-carrying circuit near the battery, as it can cause a spark.

(8) The battery vent caps should be kept in place.

(9) Do not lean over a battery when it is being charged or tested.

(10) Keep all connections tight to ensure a minimum voltage drop and to prevent arcing.

(11) The outside of the cells should be kept clean and dry to minimize self-discharge. Cells or batteries should be wiped clean with a clean cloth or rag dampened with distilled water and then wiped dry. Solvents or detergents should not be used as they may react with the case material or contaminate the battery interior.

(12) If electrolyte comes into contact with eyes, skin, or clothing, flush the eyes with plenty of clean cool water (it is recommended that flushing be continued for 15 minute). Secure medical attention immediately. Be sure to tell the medical personnel whether the electrolyte was acid or alkaline, as the treatment is different.

d. Lead-Acid Battery General Safety Requirements. The following additional safety precautions apply to lead-acid batteries.

(1) Promptly neutralize and remove any spilled electrolyte with a soda/water (1 pound per gallon) solution. If using the neutralizer solution on the top of a cell, take care to prevent the solution from getting into the cell. A prepared bottle of neutralizer solution should be kept readily available.

(2) If electrolyte comes into contact with eyes, skin, or clothing, flush with water immediately and then neutralize with a soda/water solution (1 pound of soda per gallon of water). Secure medical attention in case of skin contact.

(3) When preparing electrolyte, pour the concentrated acid into the water. NEVER POUR WATER INTO CONCENTRATED ACID. Pouring water into acid releases heat which may be sufficient to cause localized boiling and splashing, resulting in personal injury. Use a plastic or rubber container. Allow the electrolyte to cool before adding to a cell.

(4) Never use hydrometers, thermometers, filler bulbs or tools that have been used with alkaline cells as they may be contaminated with alkaline material, which could cause a chemical reaction and destroy the cell or result in injury.

e. Nickel-cadmium-alkaline battery general safety requirements. The following safety precautions apply to nickel-cadmium-alkaline batteries.

(1) Promptly neutralize and remove any spilled electrolyte with a 3 percent boric acid solution or household vinegar. When using on the top of a cell, take care to prevent the solution form getting into the cell. The boric acid solution or vinegar should be kept readily available.

(2) <u>If electrolyte comes into contact</u> with skin or clothing, flush immediately with clean cool water (it is recommended that flushing be continued for 15 minutes) and seek medical attention promptly. Tell the medical personnel that the burn was due to an alkaline material rather than acidic, since the treatment is different.

(3) <u>When preparing electrolyte</u>, slowly pour the dry electrolyte into the water and mix slowly with a clean plastic paddle. Do not use a copper, zinc, galvanized steel, or aluminum container. Allow the electrolyte to cool before adding to cell.

(4) <u>Never use</u> hydrometers, thermometers, filler bulbs, or tools that have been used with acid cells as they may be contaminated with acid, which could result in a chemical reaction and destroy the cell or cause injury.

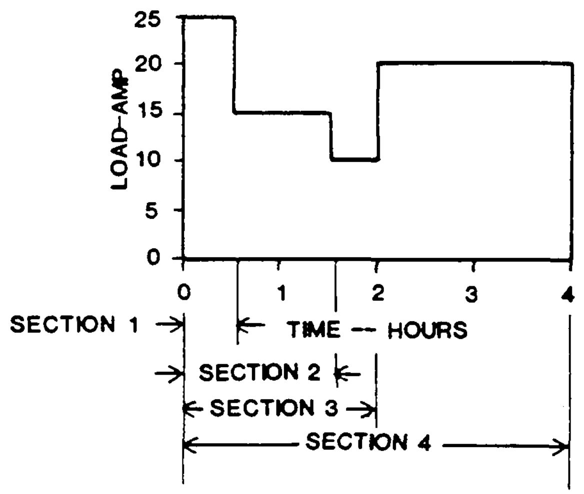
APPENDIX 1. DETERMINING BATTERY CAPACITY FOR COMPLEX LOAD

1. SCOPE. This appendix describes the method to be used in sizing a battery system for a complex (time varying) load.

2. SUMMARY OF METHOD. Basically, the method amounts to nothing more than determining the area under the load-time curve. The area is not just an integration of the time-load curve, but is an adjusted area based upon the discharge characteristics of the cell being considered. This adjustment is necessary because as the discharge rate (load) increases, the energy available decreases. The capacity is determined by successively finding the capacity required by each section of the time-load discharge starting from the beginning of the discharge cycle.

3. SIZING EXAMPLE. The following example will serve to illustrate the sizing method. Given the time-load profile shown in figure 1-1 and an end of discharge voltage of 1.75 V/c, the procedure would be as described below:

FIGURE 1-1. DISCHARGE DIAGRAM



a. For section 1, the required capacity (C_R) is:

C_R = 25 amperes for 30 minutes

b. For section 2, the C_R is:

C_R = 25 amperes for 1.5 hours minus 10 amperes for 1 hours

c. For section 3, the C_R is:

C_R = 25 amperes for 2 hours minus 10 amperes for 1.5 hours minus 5 amperes for 30 minutes plus 10 amperes for 2 hours

d. For section 4, the C_R is:

C_R = 25 amperes for 4 hours minus 10 amperes for 3.5 hours minus 5 amperes for 2.5 hors plus 10 amperes for 2 hours.

4. CAPACITY REQUIRED. The required battery capacity will be equal to whichever section gives the largest results. Since period 3 is followed by a larger demand, the calculation for section 3 is not required.

5. USE OF MANUFACTURER'S CURVES. Most lead-acid battery manufacturers publish performance curves. The form and information varies between manufacturers, but all curves show time and discharge current in terms of amperes per positive plate. Figure 1-2 on the following page is one such curve. Table 1-1 lists the discharge that can be determined from the figure.

TABLE 1-1. BATTERY PERFORMANCE DATA

TIME HOURS	RATE PER POSITIVE PLATE
4.0	10.5
3.5	11.5
2.5	15.0
2.0	17.5
1.5	21.0
1.0	27.0
0.5	38.0

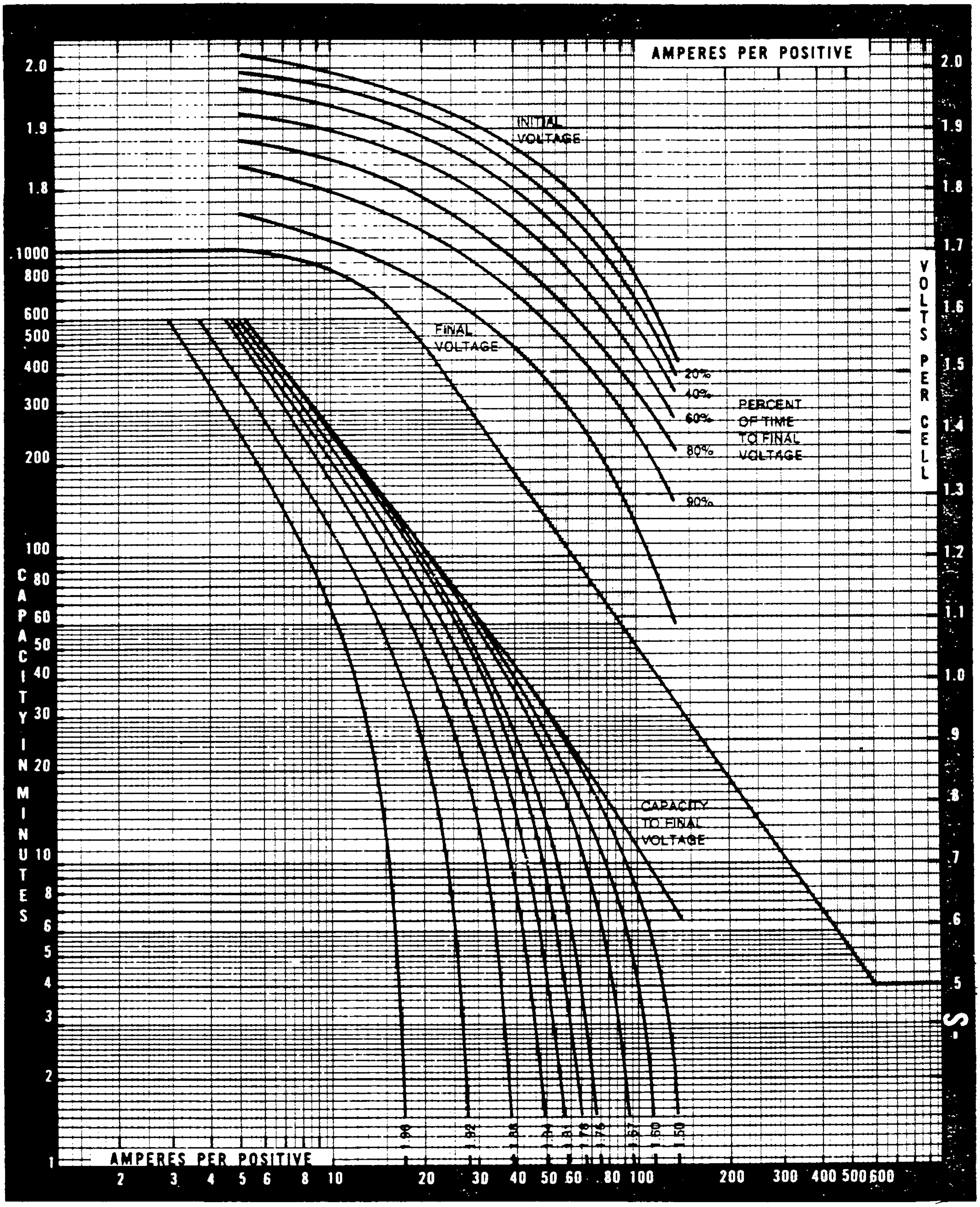
6. DETERMINING THE NUMBER OF PLATES. Using the times and discharge rates listed above, the number of positive plates required for section 1, 2 and 4 of the discharge cycle are as follows:

a. For section 1, the number of plates (positive) is:

No. Plates = 25/8 = 0.7

b. For section 2, the number of plates is:

FIGURE 1-2. DISCHARGE CURVE



No. Plates = 25/20.5 minus 10/127 = 0.8

c. For section 4, the number of plates is:

No. Plates = 25/10.5 minus 10/11.5 minus 5/15 plus 10/17.5 = 1.7

d. Since a fractional part of a plate is not available, the battery would have two positive plates. The battery would thus have a total of 5 plates.

7. TABULAR DATA. Some battery manufacturer's do not publish performance curves, but give performance data in tables. If the number of plates is given with the data, then a discharge curve can be constructed. If, however, the number of plates is not given, a performance factor K, can be determined from the tabular data. This is accomplished by plotting the discharge time versus the ratio of normal ampere hours to the discharge at the discharge time. Table 1-2 lists the published discharge data for one of the cells our of the group of cells used in the previous example.

TABLE 1-2. DISCHARGE DATA

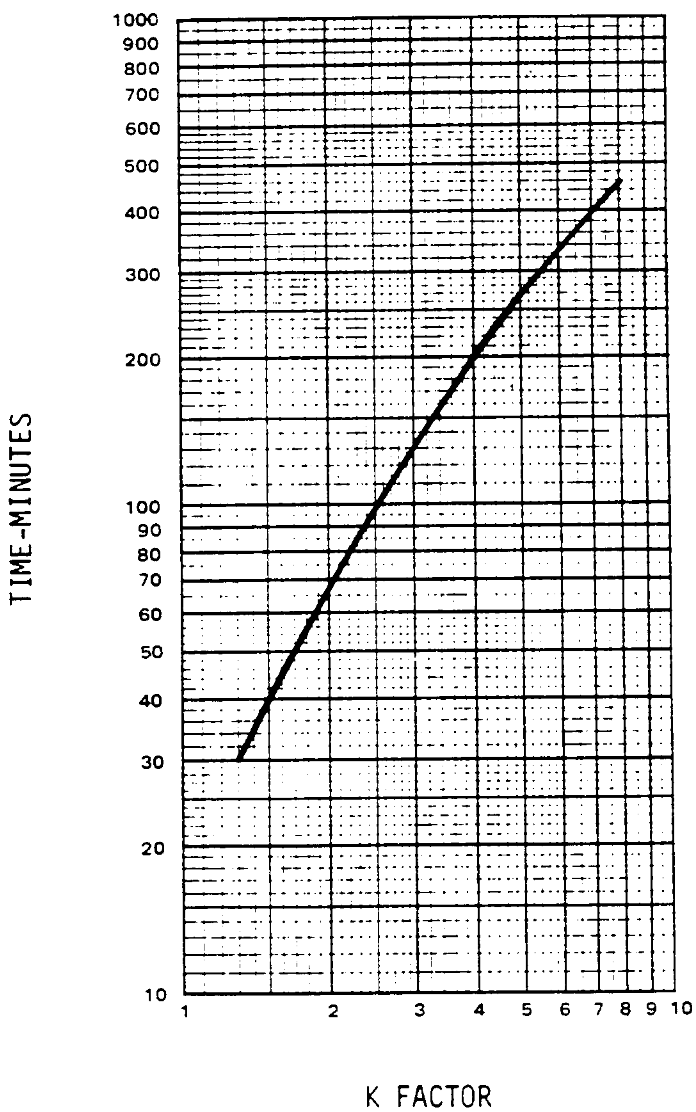
DISCHARGE TIME (HR)	DISCHARGE AMPERES
8	6.3
5	8.8
4	10.4
3	12.9
2	17.3
1.5	21.0
1	27.0
0.5	37.8

8. DETERMINATION OF FACTOR K. The capacity of the battery is 50.4 AH (6.3 amperes X 8 hours). The K factor for each discharge period is found by dividing the 50.4 AH by the discharge rate (amperes) given in table 1-2. The result is shown in table 1-3 and figure 1-3.

TABLE 1-3. K FACTORS

TIME HR	K
8	8.0
5	5.7
4	4.8
3	3.9
2	2.9
1.5	2.4
1	1.9
0.5	1.3

FIGURE 1-3. BATTERY K FACTOR



9. CALCULATING CAPACITY USING K. Using figure 1-3 to find the appropriate K factor and applying them to discharge sections 1, 2 and 4 (paragraph 3), the following capacities are obtained.

a. For section 1:

$$C_R = 25 \times K \text{ factor for 30 minutes}$$
$$= 25 \times 1.3$$
$$= 32.5 \text{ AH}$$

b. For section 2:

$$C_R = 25 \times K \text{ for 1.5 hours minus } 10 \times K \text{ for 1 hour}$$
$$= 25 \times 2.4 \text{ minus } 10 \times 1.9$$
$$= 41 \text{ AH}$$

c. For section 4:

$$C_R = 25 \times K \text{ for 4 hours minus } 10 \times K \text{ for 3.5 hours minus } 5 \times K \text{ for 2.5 hours plus } 20 \times K \text{ for 2 hours}$$
$$= 25 \times 4.8 \text{ minus } 10 \times 4.4 \text{ minus } 5 \times 3.4 \text{ plus } 20 \times 2.9$$
$$= 88 \text{ AH}$$

10. COMPARISON OF RESULTS. The one positive plate cell of the group has a capacity of 50.4 AH. If we divide the 88 AH determined by using the K factor, by 50.4, the result will be 1.8 cells or 1.8 plates. This agrees with the results obtained by using figure 1-2 within the reading accuracy of the curve.

11. RANDOM LOADS. If the discharge cycle includes a random load, the battery capacity is first determined for the load as described above without the random load. The battery capacity required for only the random load is then determined. The total capacity required is the sum of the capacity required for the discharge cycle plus the capacity required by the random load.

APPENDIX 2. TEMPERATURE CONVERSION TABLE

CONVERSIONS FROM A GIVEN REFERENCE TEMPERATURE (DEGREES F OR C) IN EACH CENTER COLUMN TO DEGREES CENTIGRADE (LEFT COLUMN) OR DEGREES FAHRENHEIT (RIGHT COLUMN).

$C = 5(F - 32)/9 \quad F = (9/5)C + 32$

DEGREES CENT.	REF TEMP	DEGREES FAHR.	DEGREES CENT.	REF TEMP	DEGREES FAHR.
(C<------F)or(C----->F)			(C<------F)or(C----->F)		
-53.9C	-65	-85.0F	-33.9C	-29	-20.2F
-53.3C	-64	-83.2F	-33.3C	-28	-18.4F
-52.8C	-63	-81.4F	-32.8C	-27	-16.6F
-52.2C	-62	-79.6F	-32.2C	-26	-14.8F
-51.7C	-61	-77.8F	-31.7C	-25	-13.0F
-51.1C	-60	-76.0F	-31.1C	-24	-11.2F
-50.6C	-59	-74.2F	-30.6C	-23	-9.4F
-50.0C	-58	-72.4F	-30.0C	-22	-7.6F
-49.4C	-57	-70.6F	-29.4C	-21	-5.8F
-48.9C	-56	-68.8F	-28.9C	-20	-4.0F
-48.3C	-55	-67.0F	-28.3C	-19	-2.2F
-47.8C	-54	-65.2F	-27.8C	-18	-0.4F
-47.2C	-53	-63.4F	-27.2C	-17	1.4F
-46.7C	-52	-61.6F	-26.7C	-16	3.2F
-46.1C	-51	-59.8F	-26.1C	-15	5.0F
-45.6C	-50	-58.0F	-25.6C	-14	6.8F
-45.0C	-49	-56.2F	-25.0C	-13	8.6F
-44.4C	-48	-54.4F	-24.4C	-12	10.4F
-43.9C	-47	-52.6F	-23.9C	-11	12.2F
-43.3C	-46	-50.8F	-23.3C	-10	14.0F
-42.8C	-45	-49.0F	-22.8C	-9	15.8F
-42.2C	-44	-47.2F	-22.2C	-8	17.6F
-41.7C	-43	-45.4F	-21.7C	-7	19.4F
-41.1C	-42	-43.6F	-21.1C	-6	21.2F
-40.6C	-41	-41.8F	-20.6C	-5	23.0F
-40.0C	-40	-40.0F	-20.0C	-4	24.8F
-39.4C	-39	-38.2F	-19.4C	-3	26.6F
-38.9C	-38	-36.4F	-18.9C	-2	28.4F
-38.3C	-37	-34.6F	-18.3C	-1	30.2F
-37.8C	-36	-32.8F	-17.8C	0	32.0F
-37.2C	-35	-31.0F	-17.2C	1	33.8F
-36.7C	-34	-29.2F	-16.7C	2	35.6F
-36.1C	-33	-27.4F	-16.1C	3	37.4F
-35.6C	-32	-25.6F	-15.6C	4	39.2F
-35.0C	-31	-23.8F	-15.0C	5	41.0F
-34.4C	-30	-22.0F	-14.4C	6	42.8F

APPENDIX 2. TEMPERATURE CONVERSION TABLE

CONVERSIONS FROM A GIVEN REFERENCE TEMPERATURE (DEGREES F OR C) IN EACH CENTER COLUMN TO DEGREES CENTIGRADE (LEFT COLUMN) OR DEGREES FAHRENHEIT (RIGHT COLUMN).

$$C = 5(F - 32)/9 \quad F = (9/5)C + 32$$

DEGREES CENT.	REF TEMP	DEGREES FAHR.	DEGREES CENT.	REF TEMP	DEGREES FAHR.
(C<------F)	or	(C----->F)	(C<------F)	or	(C----->F)
-13.9C	7	44.6F	6.7C	44	111.2F
-13.3C	8	46.4F	7.2C	45	113.0F
-12.8C	9	48.2F	7.8C	46	114.8F
-12.2C	10	50.0F	8.3C	47	116.6F
-11.7C	11	51.8F	8.9C	48	118.4F
-11.1C	12	53.6F	9.4C	49	120.2F
-10.6C	13	55.4F	10.0C	50	122.0F
-10.0C	14	57.2F	10.6C	51	123.8F
-9.4C	15	59.0F	11.1C	52	125.6F
-8.9C	16	60.8F	11.7C	53	127.4F
-8.3C	17	62.6F	12.2C	54	129.2F
-7.8C	18	64.4F	12.8C	55	131.0F
-7.2C	19	66.2F	13.3C	56	132.8F
-6.7C	20	68.0F	13.9C	57	134.6F
-6.1C	21	69.8F	14.4C	58	136.4F
-5.6C	22	71.6F	15.0C	59	138.2F
-5.0C	23	73.4F	15.6C	60	140.0F
-4.4C	24	75.2F	16.1C	61	141.8F
-3.9C	25	77.0F	16.7C	62	143.6F
-3.3C	26	78.8F	17.2C	63	145.4F
-2.8C	27	80.6F	17.8C	64	147.2F
-2.2C	28	82.4F	18.3C	65	149.0F
-1.7C	29	84.2F	18.9C	66	150.8F
-1.1C	30	86.0F	19.4C	67	152.6F
-0.6C	31	87.8F	20.0C	68	154.4F
0.0C	32	89.6F	20.6C	69	156.2F
0.6C	33	91.4F	21.1C	70	158.0F
1.1C	34	93.2F	21.7C	71	159.8F
1.7C	35	95.0F	22.2C	72	161.6F
2.2C	36	96.8F	22.8C	73	163.4F
2.8C	37	98.6F	23.3C	74	165.2F
3.3C	38	100.4F	23.9C	75	167.0F
3.9C	39	102.2F	24.4C	76	168.8F
4.4C	40	104.0F	25.0C	77	170.6F
5.0C	41	105.8F	25.6C	78	172.4F
5.6C	42	107.6F	26.1C	79	174.2F
6.1C	43	109.4F	26.7C	80	176.0F

APPENDIX 2. TEMPERATURE CONVERSION TABLE

CONVERSIONS FROM A GIVEN REFERENCE TEMPERATURE (DEGREES F OR C) IN EACH CENTER COLUMN TO DEGREES CENTIGRADE (LEFT COLUMN) OR DEGREES FAHRENHEIT (RIGHT COLUMN).

$$C = 5(F - 32)/9 \quad F = (9/5)C + 32$$

DEGREES CENT. (C<------	REF TEMP F)or(C	DEGREES FAHR. ----->F)
27.2C	81	177.8F
27.8C	82	179.6F
28.3C	83	181.4F
28.9C	84	183.2F
29.4C	85	185.0F
30.0C	86	186.8F
30.6C	87	188.6F
31.1C	88	190.4F
31.7C	89	192.2F
32.2C	90	194.0F
32.8C	91	195.8F
33.3C	92	197.6F
33.9C	93	199.4F
34.4C	94	201.2F
35.0C	95	203.0F
35.6C	96	204.8F
36.1C	97	206.6F
36.7C	98	208.4F
37.2C	99	210.2F
37.8C	100	212.0F
38.3C	101	213.8F
38.9C	102	215.6F
39.4C	103	217.4F
40.0C	104	219.2F
40.6C	105	221.0F
41.1C	106	222.8F
41.7C	107	224.6F
42.2C	108	226.4F
42.8C	109	228.2F
43.3C	110	230.0F
43.9C	111	231.8F
44.4C	112	233.6F
45.0C	113	235.4F
45.6C	114	237.2F
46.1C	115	239.0F
46.7C	116	240.8F
47.2C	117	242.6F

DEGREES CENT. (C<------	REF TEMP F)or(C	DEGREES FAHR. ----->F)
47.8C	118	244.4F
48.3C	119	246.2F
48.9C	120	248.0F
49.4C	121	249.8F
50.0C	122	251.6F
50.6C	123	253.4F
51.1C	124	255.2F
51.7C	125	257.0F
52.2C	126	258.8F
52.8C	127	260.6F
53.3C	128	262.4F
53.9C	129	264.2F
54.4C	130	266.0F
55.0C	131	267.8F
55.6C	132	269.6F
56.1C	133	271.4F
56.7C	134	273.2F
57.2C	135	275.0F
57.8C	136	276.8F
58.3C	137	278.6F
58.9C	138	280.4F
59.4C	139	282.2F
60.0C	140	284.0F
60.6C	141	285.8F
61.1C	142	287.6F
61.7C	143	289.4F
62.2C	144	291.2F
62.8C	145	293.0F
63.3C	146	294.8F
63.9C	147	296.6F
64.4C	148	298.4F
65.0C	149	300.2F
65.6C	150	302.0F

APPENDIX 3. BATTERY SELECTION AND SIZING EXAMPLE

1. GENERAL For the purpose of this example, a second-generation VORTAC facility in the Indianapolis sector will be used. The data used is for discussion purposes only and in no way reflects on actual facility operation and/or equipment.

2. STEP 1 - Collect D.C. power requirements. Fill out the data sheet from all available information that is known about the installation (see figure 3-1).

3. STEP 2 - Select battery type. Since system is designed for continuous float charge standby operation, a Type I battery is selected.

4. STEP 3 - Determine maintenance interval. Since system will be maintained on a semiannual basis, Class 1 maintenance battery is selected.

5. STEP 4 - Special requirements. Since batteries are in a fixed installation, Style B is not required. Style A is selected as being more cost effective.

6. STEP 5 - Determine if environmental conditioning is required. Since the battery environment is well above 32 degrees fahrenheit and below 12 degrees fahrenheit, no heating or cooling is required.

7. STEP 6 - Select battery chemistry. Since the battery will remain discharged 24 hours or less, lead-acid battery is selected.

8. STEP 7 - Determine battery capacity.

a. Rate Correction. Since the discharge is continuous constant current, the capacity is current times time. Otherwise the method in appendix 1 must be used. Since battery ampere-hours are normally specified at the 8-hour rate, the 2-hour discharge will require a corrected 8-hour rate to be determined.

Uncorrected capacity of the battery is equal to the operating current (41.7 amps) times discharge current duration (2 hours).

Capacity uncorrected = 41.7 amps for 2 hours = 83.4 A-H

Rate = 41.7 amps continuous load

The discharge rate or C rate is = C/(A-H/I), i.e., C/(83.4/41.7) = C/2

From Table 3-2, C/2 yields 26% of rated capacity based on 8-hour rate, therefore, the rate corrected capacity is:

83.4 A-H / 0.26 = 320.8 A-H

b. Temperature Correction. No correction is necessary for temperatures above 77 degrees fahrenheit. However, for temperatures below 77 degrees fahrenheit, battery capacity must be increased. From Table 2-1, at 60 degrees fahrenheit, only 90 percent of rated capacity is available based on the 8-hour rate. The corrected capacity is:

320.8 A-H / 0.9 = 356.4 A-H

9. STEP 8 - Selecting the number of cells and cutoff voltage.

Batteries connected to equipment during charge.

$$\frac{\text{Equipment upper operating limit}}{\text{Typical equalize voltage for battery recharge}} =$$

27.6V / 2.30V = 12.0

Rounded down = 12 cells

Typical cutoff voltage for chemistry selected times number of cells selected

1.75V * 12 = 21.0V

21.0V is below equipment nominal operating voltage, yet still above equipment lower operational range, number of cells selected is sufficient.

10. STEP 9 - Determine battery charge requirements. Existing charger will provide maximum voltage for equalize (see step 8). Battery charger current sufficient for load and batteries. Load is 41.7 amps. Batteries requires 4 amps for 24 hours to replace 98.1 A-H (83.4 A-H / 85 percent efficiency). Total maximum required current is (41.7 amps plus 4 amps) 45.7 amps which is within the 50 amps available.

11. DETERMINE BATTERY PARAMETERS. At this point, remaining battery parameters can be determined.

FIGURE 3-1 SAMPLE BATTERY FACILITY DATA SHEET

FACILITY BATTERY SELECTION
DATA SHEET

Date **5 Jan 1986**

Selecting Office **INDIANAPOLIS SFO**

Where Battery to be used (Facility/Equipment)

INDIANAPOLIS VORTAC/SECOND GENERATOR VORTAC

Describe application or Use of Battery to be Selected
STANDBY POWER - FLOAT CHARGE

Scheduled Maintenance Interval **SEMIANNUAL**

Maintainability Considerations **SYSTEM VOLTAGE AND CURRENT**
CAN BE MONITORED REMOTELY

Special Requirements (All-Position Use) (Chemical Compatibility) (Gassing Manifold) (etc) **None**

Remarks

FIGURE 3-1 SAMPLE BATTERY FACILITY DATA SHEET
(Continued)

FACILITY BATTERY SELECTION DATA SHEET

Facility Application Environments (Operational Battery Ambients)

Minimum Expected Temperature **60** ^{o}F Duration ______

Maximum Expected Temperature **80** ^{o}F Duration ______

Normal Expected Temperature **72** ^{o}F Duration ______

Describe Unusual Conditions (Shock) (Vibration) (Rain)

(Sunlight) (Altitude) (Dust) (etc.) **None**

Battery Discharge Load Profile Into Equipment

Maximum Voltage Tolerated **(24 + 15%) 27.6** Volts

Lowest Voltage for Required Performance **20.4** Volts

Maximum Current (inrush, spikes) **41.7** Amps

Normal Operating Current **41.7** Amps

Complex Load Considerations (see Appendix ______)

Constant Load

Discharge Duration **2 hours**

Maximum Calculated Ampere-Hours Capacity (Include any design safety margins) ______ Ampere-Hours

Anticipated Frequency of Deep (>75%) Discharge ______%

FIGURE 3-1 SAMPLE BATTERY FACILITY DATA SHEET
(Continued)

FACILITY BATTERY SELECTION DATA SHEET

Charge Characteristics Available

Charger power from: (Commercial line, renewable energy, etc.) **Commercial Line**

When is Recharge Started **Normally within 2 hours of use**

Time Available for Recharge **24** Hours

Maximum Voltage to Battery **28** Volts

Maximum Current to Battery **50** Amps

Method of Recharge (Constant Potential)

(Constant Current) (Hybrid Description) (Pulse Charging)

Constant Potential

Miscellaneous/Other